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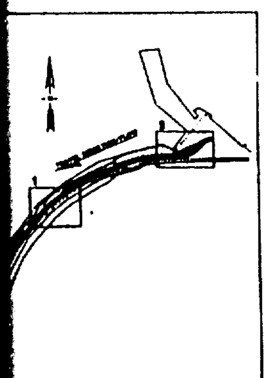

HYDRAULICS LABORATORY

(2)

TECHNICAL REPORT HL-90-11

SHIP NAVIGATION SIMULATOR STUDY SACRAMENTO RIVER DEEPWATER SHIP CHANNEL PROJECT, SACRAMENTO, CALIFORNIA

Report 1
PHASE I

Volume I
Main Text and Appendix A

by

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19. ABSTRACT (Continue on reverse if necessary and identify by block number)

A real-time ship simulation investigation of the proposed design for deepening the man-made canal portion of the Sacramento Deepwater Ship Channel, Sacramento, CA, was conducted. The purpose of this study was to determine if the navigation channel could be deepened from 30 to 35 ft without widening from the existing channel width of 200 ft or if the channel would require widening to 250 ft, as authorized. A numeric model of the existing ship channel from about channel mile 35 to the Sacramento Harbor was developed. This model was verified by a member of the San Francisco Bar Pilots Association. Numeric models of two plan conditions were also developed, one with the existing channel deepened to 35 ft and the other with the channel widened by 50 ft and deepened to 35 ft. In both plans the two bends were widened by 50 ft. Tests were run on the WES ship simulator in which six pilots from the San Francisco Bar Pilots Association conned the simulated ship through the three simulated channel conditions.

These tests demonstrated that there was little difference between navigation of ships

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in the existing channel and in the proposed channel which was deepened but not widened in the straight reaches. Slightly but consistently better control is evident in the proposed channel. Larger bank clearances were evident with the 50-ft widening. Also, control of the ship appeared to be easier. The wider channel would provide more allowance for error, drift, and wind effects on the ships; however, the existing channel is not considered a navigation problem.

Appendix B presents track plots of each pilot's runs and Appendix C presents bar charts of statistical parameters in comparison format in addition to those discussed in the main text.

It is recommended that when the Sacramento Deepwater Ship Channel from mile 18.6 to the Sacramento Harbor is deepened by 5 ft (from 30 to 35 ft), the straight sections can remain 200 ft wide and the turns should be widened to 250 ft.

PREFACE

This investigation was performed by personnel of the Hydraulics Laboratory of the US Army Engineer Waterways Experiment Station (WES) as authorized by the US Army Engineer District, Sacramento (SPK). The study was conducted with the WES research ship simulator. SPK provided the essential field and model data required. This report is one of a series describing the test program and results of Phase I of a study of the man-made canal portion of the project. Phase II of this study involved the river portion of the project from the man-made canal to below the Rio Vista bridge and is described in other reports of this series.

The investigation was conducted during the period December 1987 to June 1989 by Ms. Rosalyn HoangThi Nguyen and Dr. Larry L. Daggett of the Ship Simulation Group, under the general supervision of Messrs. Frank A. Herrmann, Jr., Chief of the Hydraulics Laboratory; R. L. Sager, Assistant Chief of the Hydraulics Laboratory; and M. B. Boyd, Chief of the Waterways Division.

Acknowledgement is made to Messrs. Mike Campbell and Eric Polson, Engineering Division, SPK, for their cooperation and assistance at various times throughout the investigation. Special thanks should go to the San Francisco Bar Pilots Association for furnishing professional pilots to con the ship during the simulator tests on the WES ship simulator. The numeric model of the ship was developed by Tracor Hydronautics, Inc., Laurel, MD, under contract to WES.

Commander and Director of WES during preparation of this report was COL Larry B. Fulton, EN. Technical Director was Dr. Robert W. Whalin.

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* A limited number of copies of Appendixes B and C were published under separate cover. Copies are available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

CONVERSION FACTORS, NON-SI TO SI (METRIC)
UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
acre-feet	1,233.489	cubic metres
degrees (angle)	0.01745329	radians
feet	0.3048	metres
knots (international)	0.5144444	metres per second
miles (US statute)	1.609347	kilometres
square miles	2.589998	square kilometres

SHIP NAVIGATION SIMULATOR STUDY, SACRAMENTO RIVER DEEPWATER SHIP CHANNEL PROJECT SACRAMENTO, CALIFORNIA

PHASE I

PART I: INTRODUCTION

Physical Description

1. The Sacramento River Deepwater Ship Channel is located in the Sacramento-San Joaquin Delta region of northern California. The 46.5-mile-long* channel lies within Contra Costa, Solano, Sacramento, and Yolo Counties and serves the marine terminal facilities at the Port of Sacramento (Figure 1). The Sacramento River Deepwater Ship Channel joins the 35-ft-deep San Francisco to Stockton, CA, navigation project (John F. Baldwin and Stockton Ship Channels) at New York Slough, thereby affording access from the Port of Sacramento to bay area harbors and the Pacific Ocean.

2. The existing Sacramento Deepwater Ship Channel Project was authorized by the River and Harbor Act** approved 24 July 1946. The principal features of the project as authorized by this act include the deepwater ship channel, harbor, and canal. The harbor consists of a turning basin of the same depth as the ship channel (30 ft), 1,000 ft wide and 1,200 ft long. The barge canal, 11 ft deep and 120 ft wide with lock and drawbridge, connects the harbor and Sacramento River. The deepwater ship channel is 30 ft deep and 200 to 300 ft wide from deep water in Suisun Bay to the turning basin. The project has been in operation for oceangoing vessels since June 1963.

3. Most of the water from the 64,000-square-mile Central Valley watershed, or roughly one-third of the entire State of California, drains through the Sacramento-San Joaquin Delta. The water originates as runoff from winter rains in the valley and foothills and spring snowmelt from the Sierra Mountains. Three-quarters of the total annual flow occurs between January and May, with January and February being the peak months. The main tributary

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* A table of factors for converting non-SI units of measurement to SI (metric) units of measurement is found on page 3.

** 79th Congress. 1946 (24 Jul). "River and Harbor Act," Public Law 525.

rivers to the delta include the Sacramento, which produces 80 percent of the total runoff; the San Joaquin (15 percent); and other minor tributaries (5 percent). Before large-scale water diversions began, the mean annual outflow from the delta was more than 30 million acre-ft. The construction of many Federal. State, and local water projects within the watershed has cut the flow to its present level of about 16 million acre-ft per year.

4. Water elevations in the area are influenced by hydrologic and tidal phenomena. Rapid melting of snowpacks and rains in the watersheds of the tributaries may greatly influence the waterways in the area. The combination of heavy runoff and tidal action may produce flood stages. Tidal action is an important factor in the development of any plan to improve the navigability of waterways in the study area. Tidal ranges for an average tide and low advective outflow are 4.5 ft at Collinsville, 4.75 ft at Junction Point, and 6.0 ft at the Port of Sacramento.

5. The closed upstream end of the Sacramento River Deepwater Ship Channel and the constrictive geometry of the channel complicate the tidal hydraulics of the ship channel between Junction Point and the Port of Sacramento. The tidal amplitude increases as a result of a harmonic oscillation created by the closed end of the channel. The constrictive geometry increases the tidal effect. As a result, the average tidal range at the port is 6.0 ft, whereas the average tide range nearby for the riverside of the lock is approximately 2.5 ft during periods of low flow.

Proposed Channel Improvement

6. The proposed channel improvement for the Sacramento River Deepwater Ship Channel involved modification to three portions of the project reach:

a. New York Slough to Junction Point (channel miles 0 to 15.0): This portion of the channel was planned to be deepened from 30 to 35 ft, and the width increased from 300 to 350 ft.

b. Junction Point to the entrance to the man-made channel (channel miles 15.0 to 18.6): The width would remain 300 ft along this reach, and the depth would be increased from 30 to 35 ft.

c. The entrance to the man-made channel to the Port of Sacramento (channel miles 18.6 to 46.5): This portion would be deepened from 30 to 35 ft, and the width increased from 200 to 250 ft.

7. Channel slopes were planned to be 1V on 4H in the reach between

New York Slough and channel mile 18.6 and 1V on 3H from channel mile 18.6 to the Port of Sacramento.

8. The selected plan as discussed in paragraph 6 and as presented in the General Design Memorandum (GDM)* was to deepen the existing one-way channel between New York Slough and the Port of Sacramento to 35 ft below el -2** and to widen the channel according to the dimensions in the following tabulation:

	Existing, ft			GDM, ft		
Reach	Depth	Width	Slope	Depth	Width	Slope
New York Slough to mile 15.0	30	300	1V:4H	35	350	1V:4H
Mile 15.0 to mile 18.6	30	300	1V:4H	35	300	1V:4H
Mile 18.6 to Port of Sacramento	30	200	1V:3H	35	250	1V:3H

Purpose and Scope of Investigation

9. The purpose of the ship simulator investigation was to determine the effect of deepening the Sacramento Deepwater Ship Channel. The investigation was also conducted to determine if the channel could be deepened without widening in the straight reaches of the man-made portion of the channel and still maintain adequate navigation efficiency and safety.

10. The basic plan for the ship simulator investigation was to conduct the study in two phases. The first phase included the man-made channel portion from channel mile 18.6 to 43 (Sacramento Harbor). The second phase included the lower portion from river mile 18.6 to just below the bridge at Rio Vista (river mile 11.5). This report will present only the results of Phase I of the Sacramento Deepwater Ship Channel ship simulation.

11. For Phase I, the Sacramento River scenario as implemented on the ship simulator at the US Army Engineer Waterways Experiment Station (WES) included the navigation channel from Sacramento Harbor to about river mile 35. The test section was considered to be representative of the remainder of the

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* US Army Engineer District, Sacramento. 1986 (Mar). "Sacramento River Deepwater Ship Channel; General Design Memorandum and Appendix A and Final Supplemental Environmental Impact Statement," Design Memorandum No. 1, Sacramento, CA.

** All elevations (el) cited herein are in feet referred to the National Geodetic Vertical Datum (NGVD).

man-made channel and contained the two most critical bends. The remaining portions of this channel are geometrically similar in cross section. Therefore it was not necessary to reproduce the remainder of the man-made channel. This portion of the project was considered critical to the success of the deepened project since 90 percent of the project cost depends on the size of the man-made channel.

PART II: DATA DEVELOPMENT

12. In order to simulate the study area, it is necessary to develop information relative to five types of input data:

a. The channel data base contains dimensions for the existing channel and the proposed channel modification. It includes the channel cross sections, slope angle, overbank depth, and autopilot track-line and speed definition.

b. The visual scene data base is composed of principal features of the simulated area, including the aids to navigation, buildings, and loading facilities.

c. The radar data base contains the features for the plan view of the study area.

d. The ship data file contains characteristics and hydrodynamic coefficients for the test vessels.

e. The current pattern data in the channel include the magnitude and direction of the current for each cross section defined in the channel data base.

Channel

13. The information used to develop the channel data base came from the September 1986 hydrographic survey charts furnished by the US Army Engineer District, Sacramento, and National Ocean Survey Chart No. 18662. This was the latest information available concerning depths, dimensions, and bank line of the channel. State planar coordinates as shown on the annual survey were used for the definition of the data.

14. The simulator channel for the upper part of the Sacramento River from the Sacramento Harbor, river mile 43, to river mile 35 (Figure 1) has 103 cross sections. Figure 2 shows the defined channel for the existing condition and the 30-ft contour. The 30-ft contour line generally fell inside the defined channel. The definition of the channel edge used for this simulation study was the location of the 30-ft contour line unless this was inside the authorized channel, in which case the official channel edge was used. Cross-section 15 was defined at the Union Chemical dock, and cross-section 20 was placed just below the dock as shown in Figure 2. Figures 3 and 4 present the layout of cross-sections 15 and 20, respectively, as examples of the

cross-section definitions used in this study. The upper plot is exaggerated vertically to show the differences between the existing, the proposed, the simulated, and the actual channel cross sections. The plan channel was the existing channel surveys deepened by 5 ft, thus preserving the existing channel shape. This contour would represent the channel shape several years after construction based on an assumption that the channel will be shaped similarly by the same forces that are presently shaping the channel. This assumption may be significant with respect to the hydrodynamic forces acting on the ship as the actual channel bottom is deeper than the design depth in the center, but less than design depth at the channel edges. It also involves irregular bank lines instead of an idealized trapezoidal channel with straight banks. The simulated channel is a good representation of the bank slope on the right side of cross-section 15 (where the dock is) and the left side of cross-section 20. The left side of cross-section 15 and the right side of cross-section 20 are more irregular and the slope of the bank within the width of one ship beam of the channel edge was used to define the bank effects. In addition, the actual width of the channel was used when the 30-ft depth was significantly beyond the authorized channel definition as on the right side of cross-section 15.

15. Channel cross sections were placed at each bend in the channel and at each surveyed cross section. The ship simulator model allows eight equally spaced points to define each cross section. At each of these points, a depth and current magnitude and direction are required. For each cross section, the width, right and left bank slopes, and overbank depth are required. These data were obtained from the hydrographic survey data provided by the Sacramento District for use in the main program for calculating bank suction forces.

16. Because the bank effects acting on a ship are such an important factor in ship handling in this waterway, special emphasis was placed on correctly modeling the banks and resulting forces and moments. The model of bank forces available on the WES simulator was not adequate for this study, and a new model was developed by Tracor Hydronautics, Inc.* This model was based

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* V. Ankudinov. 1988 (26 Jan). "Bank Effects as Programmed by Tracor Hydronautics, Inc.," unpublished contractor's report, Tracor Hydronautics, Inc., Laurel, MD.

on research by Norrbin*,** and uses the latest available research data. The forces and moment generated by the banks are dependent on the ship's speed and distance from the bank, the bank shape characteristics, and overbank depths.

Visual Scene

17. The visual scene data base was created from the same maps and charts noted in the discussion of the channel. The state planar coordinate system was used as for the channel data base. Aerial and still photographs and pilot's comments obtained aboard a transiting ship during a reconnaissance trip to Sacramento constituted other sources of information for the scene. These all wed inclusion of the significant physical features present and also helped determine which, if any, features the pilots use for informal ranges and location sightings.

18. All aids to navigation such as buoys, channel markers, the dock, buildings, and tanks were included in the visual scene The section on validation lists some other objects that were added during the pilot validation.

19. The visual scene is generated in three dimensions: north-south, east-west, and vertical elevation. As the ship progresses through the channel, the three-dimensional picture is constantly transformed into a two-dimensional perspective graphic image representing the relative size of the objects in the scene as a function of the vessel's position and orientation and the viewing direction and position on the bridge. The graphics hardware used for the Sacramento project is a stand-alone computer (Silicon Graphics Iris 2300), which is connected with the main computer to obtain information for updating the viewing position and orientation. This information includes parameters such as vessel heading, rate of turn, and position. Viewing angle is also passed to the graphics computer for the look-around feature on the simulato console that enables the pilots to look at objects outside of the straight-ahead view, which encompasses only a 40-deg arc. This feature

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* N. H. Norrbin. 1985 (Jun). "Bank Clearance and Optimal Section Shape for Ship Canals," Twenty-Sixth Permanent International Association of Navigation Congresses, Brussels, 16-22 June 1985, pp 167-178.

** N. H. Norrbin. 1974. "Bank Effects on a Ship Moving Through a Short Dredged Channel," Proceedings, Tenth Symposium on Naval Hydrodynamics, Cambridge, MA, pp 71-87.

simulates the pilot's ability to see any object with a turn of his head. The pilot's position on the bridge can also be changed from the center of the bridge to any position wing to wing to simulate the pilot walking across the bridge to obtain a better view, e.g., along the edge of the ship from the bridge wing.

20. It may be noted that creating a scenario for the project area is very demanding in terms of engineering judgment. The goal of the scenario is to provide all the required data without excessive visual clutter, bearing in mind the finite memory storage and computational resources available on the minicomputer.

Radar

21. The radar data base is used by the Geneisco graphic image generator to create a simulated radar for use by the test pilots. The radar data base contains x- and y-coordinates that define the border between land and water. The file also contains coordinates for any major physical feature deemed important such as buildings, bridges, tanks, docks, and aids to navigation. In short, these data define what a pilot would actually see on a shipboard radar. The radar image is a continuously updated view of the vessel's position relative to the surrounding area. Three different scales were programmed to allow the pilot to choose which scale he preferred.

Current

22. A current data base contains current magnitude and direction at eight points across the channel at each of the cross sections defined in the channel.

23. Little current information is available for this area of the ship channel. Tidal currents based on prototype measurements taken during physical model verification field surveys in September 1967 and March 1968 were incorporated into the model. A discharge based on velocity measurements at station V-11* at mile 33.1 was calculated for both surveys, and the average discharge

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* V-11 was a verification velocity station used during the September 1967 and March 1968 Sacramento-San Joaquin Delta hydraulic verification surveys for the Corps of Engineers San Francisco Bay physical model.

at maximum ebb velocity was used for determining the velocities at each cross section. The current was assumed to be aligned with the channel thalweg and was modified according to the channel cross-sectional area at each cross section. Ebb currents were used since outbound transits of loaded ships were to be used for the simulation tests and ebb currents would create the most difficult control situations.

Test Ship

24. The ship data base consists of the ship characteristics and coefficients used in the hydrodynamic program for calculating forces on the bulk carrier used in the testing program. In addition, the bow of the ship would also be seen by the pilot in the visual scene from the ship bridge. Therefore, a visual image of the ship bow had to be created.

25. The design ship used in the simulation was the *Asian Banner*, which is 610 ft long, has a 93-ft beam, and was loaded to a 30-ft draft with 2-ft underkeel clearance for the existing condition and to 35-ft draft with 2-ft underkeel clearance for the proposed channel. A description of the ship model is included in Ankudinov.*

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* V. Ankudinov. 1988 (Sep). "Hydrodynamic and Mathematical Models for Ship Maneuvering Simulation of the Bulk Carrier 'Asian Banner' in Deep and Shallow Waters, and Bank Effects Module in Support of WES Sacramento Channel Study," Technical Report 87005.02-1, prepared under Contract No. DACW39-87-D-0029 by Tracor Hydronautics, Inc., Laurel, MD, for US Army Engineer Waterways Experiment Station, Vicksburg, MS.

PART III: NAVIGATION STUDY

Validation Tests

26. For the purpose of validating the simulation of Phase I of Sacramento Deepwater Ship Channel, a member of the San Francisco Bar Pilots Association conducted tests on the ship simulator prior to the actual testing. The purpose of the validation tests was to verify and fine-tune, as necessary, model parameters such as tidal current, bank effects, wind, the ship model, and objects in the visual scene based on the pilot's experience and familiarity with the study area.

27. The validation tests were conducted on the ship simulator for the existing channel scenarios on the upper reach of the Sacramento Deepwater Ship Channel. Outbound tests were run with ebb tide currents.

28. Ship hydrodynamic coefficients and bank effect factors were adjusted based on the pilot's comments during the validation tests. In addition to the tuning of the bank effects and the design ship model, the pilot suggested a different color for the levee, a different range for radar view, lowering the height of the levee, increasing the size of the rear ranges, and relocating the ranges (there was conflicting information as to the range location). Upon leaving, the pilot remarked on how close to reality the simulation had become following these adjustments.

Test Conditions

29. As described in paragraph 11, the Sacramento Deepwater Ship Channel scenario as implemented on the WES ship simulator included the navigation channel from the Sacramento Harbor, river mile 43, to river mile 35 (Figure 1). This portion of the channel is generally straight and was originally trapezoidal in shape with a 90-deg turn immediately past the harbor area and a smaller 31-deg bend near mile 35. The pilot testing was conducted with three different channels (Figure 5): (a) Plan 0, the existing condition with 200-ft width and channel depth based on the most recent hydrographic survey available; (b) Plan 1, the proposed channel, deepened by 5 ft with the existing width of 200 ft in the straight reaches, but widened to 250 ft in the curved segments; (c) Plan 2, a channel that is widened to 250 ft throughout the

channel and deepened by 5 ft. The design ship was based on the *Asian Banner*, described in paragraph 25. A few additional runs were made with an 855-ft bulk carrier with a 106-ft beam and the same load conditions as before in the wider and deeper channel (Plan 2) since the pilots commented that such ships have called on the Sacramento Port. Small ebb tidal currents based on prototype measurements were incorporated into the model. The current was assumed to be aligned with the channel thalwag. A southwesterly wind of 15 knots was also included in some of the test conditions. Only outbound transits were simulated in the three different channels since almost all loaded transits are export shipments and the channel changes will widen the effective channel for ballasted ships with a draft less than 30 ft.

Test Procedure

30. Formal pilot testing was conducted with six professional pilots from the San Francisco Bar Pilots Association. The purpose of the testing was to determine the effect of the deepening and widening plans for the Sacramento Deepwater Ship Channel on ship handling. Involving the local professional pilots incorporated their skill, experience, and familiarity with handling ships in the study area into this evaluation. The pilots were briefed on the study and introduced to the equipment after which they conducted several familiarization runs in the simulated existing channel before they started the actual testing. To avoid fatigue, the pilots alternated conning the simulator as each run required approximately an hour to complete. A total of 70 runs were made over 12 days of testing. A complete list of test runs is presented in Table 1.

Test Results

31. The warmup runs performed by the pilots were not included in Table 1 nor in the test analysis. During each run, the characteristic parameters of the ship were automatically recorded every 10 sec. These parameters included the position of the ship's center of gravity, speed, revolutions per minute (rpm) of the engine, heading, drift angle, rate of turn, rudder angle, and port and starboard clearances.

32. The simulator tests were evaluated based on pilot ratings, ship

tracks, and statistical analysis of various ship control parameters recorded during testing. The following sections will discuss results from these three methods of analysis.

Pilot Rating

33. To determine what the pilots thought about the simulator and the proposed deepening, two questionnaires were prepared to document their comments and rate the runs. One was given to the pilots after each run and a final debriefing questionnaire was given after the pilots' 4-day test period. For each run, the pilots were asked to give a rating on the difficulty of ship handling, the degree of attention required, the danger of grounding, the danger of ramming, and the realism of the handling of the simulator for the following areas: A, from the entrance of the channel at the upper end through the bend to the start of the straight reach; B, the straight reach of the channel; and C, the lower turn of the channel just above river mile 35 (Figure 5). The rating form and individual ratings of the pilots are included in Appendix A.

34. Figure 6 shows the average score of the pilots' ratings for the following test conditions with the existing channel (Plan 0): no current, no wind; with current, no wind; and with current and with wind. The lower the rating, the safer the condition as perceived by the pilots. The realism of the handling of the simulator received a high rating by the pilots. In general, for the other rated categories, a lower rating was recorded in the presence of the current. In the presence of the wind, the pilots' ratings were higher. The wind appeared to cause significant difficulty, but the current seemed to make the ship handling slightly easier. A higher degree of difficulty and attention required were indicated in areas A and C. The danger of ramming was rated more highly in area A where the dock is located than in other areas. The ratings show the pilots experienced more difficulty in the two turns than in the straight reach. These results are consistent with expectations.

35. Figure 7 compares the pilots' ratings of different plans. The realism of the handling of the simulator received a high rating by the pilots. Areas A and C were rated high on degree of difficulty and attention required. The dangers of grounding and ramming were rated high in Plan 2 for area A

despite the fact that in this area there is no difference between plans. The pilots' ratings show the pilots had more difficulty in the two turns than in the straight reach. The amount of attention required and the danger of grounding were about the same for all plans with the design ship. The danger of ramming or grounding, the degree of difficulty, and attention required show no significant differences between Plans 0 and 1. The larger bulk carrier was rated more difficult to handle with a higher degree of danger of grounding and ramming in area C than the design ship. In area A the ratings were not significantly different from the design ship results. It should be noted that all the pilots stated in the final debriefing questionnaires that they felt the 35-ft-deep, 250-ft-wide channel (Plan 2) was preferred since the vessel would feel less bank suction, cause less bank erosion, and have more room to allow for set, drift (particularly with wind on ballasted ships), and pilot error.

Composite Ship Track Plots

36. A complete set of the individual run ship track plots for the three channel test conditions is presented in Appendix B. Composite ship track plots for the pilot testing are presented in Figures 8-24. The track-lines are shown by overlaid rectangular blocks indicating the ship's location at different times during the transit. In addition, lines showing the defined channel are included, along with the water/land intersection or bank line and the top of the levee. Dots also mark the aids-to-navigation markers. The relative position of the ship in the defined channel is the important feature. The other features are provided for reference.

37. Figures 8-13 show composite track plots of all piloted tests for outbound transits in area A. These plots show that the pilots covered a large area at the entrance to the channel from the port and tended to get close to the lower end of the dock facility. According to the pilots, they normally get close to the port, or left, side of the channel at the channel entrance from the port to stay away from the shallow water on the starboard, or right, side of the channel. The pilots tended to stay slightly starboard of the center of the channel to use the bank suction and cushion in making the left turn. The expansion at the Union Chemical dock caused the ship to lose this bank suction on the starboard side, which in turn caused the ship to slide

toward the dock and rotate to the right. This is particularly dangerous when a ship is berthed at the dock even though the presence of the ship at the dock mitigates the loss of bank cushion. Overall, the ship track plots show no noticeable differences in navigating the channel with or without currents. The ship track plots for Plan 1 (the proposed channel) and Plan 2 (deeper-wider channel) show the pilots stayed farther away from the port side of the channel when compared to Plan 0 (existing channel). Better clearances were shown at the downstream end of the channel expansion near the dock in Plans 1 and 2. However, the blown-up view (insert 2, Figures 10 and 11) of the entrance of the channel shows the pilots managed to stay within the channel limitation. A cutback right at the entrance of the channel would help the pilots maneuver through this bend. The same general pattern was observed in all plans (0, 1, and 2). A few runs were made with the larger ship (855 ft long with a 106-ft beam). There is no noticeable difference in the paths followed by the two ship sizes as shown in Figures 12 and 13 for Plan 2.

38. Figures 14-18 show the composite track plots of all piloted tests in area B. In the straight reach, most runs are very tightly grouped and seem to have good clearance. The ship track plots show the pilots tended to get close to the starboard side of the channel coming out of the turn. With the blown-up view of the area as shown in the inserts (Figures 14-17), more clearance was observed on the port side of the channel just below the turn. The ship stayed on the outside of the channel to use the bank forces to complete the turn. There is little difference between the with-current and without-current scenarios. From the individual track plots it can be determined that one pilot traveled too fast causing the ship to lose control. This particular pilot bounced back and forth between banks. Better clearance was evident in Plan 2, the 250-ft wide channel (Figure 18), indicating the ships followed similar paths and did not meander more than in the narrower channel.

39. Figures 19-24 show the ship track plots in area C. The ship track plots show that as the pilots approached the lower turn, they moved close to the left side of the channel. The pilots seemed to slide to the port side of the channel to use bank forces to make the turn. Better clearance does appear to be evident in Plan 0; i.e., the pilots did not get as close to the port side of the channel as they did in Plan 1. However, the inserts with the blown-up view of the area (Figures 19-22) indicate there is no noticeable problem in area C. The channel turn was widened to 300 ft in Plan 2. Much

better clearance can be observed for Plan 2 (Figure 23). This extra widening appeared to help make the turn safer. However, fewer test runs were made for this condition than the others, and these results should be used with caution.

Statistical Analysis

40. As mentioned in paragraph 31, during each run, the control parameters of the ship were recorded every 10 sec. These parameters are listed in paragraph 31. Since the simulator performances of nearly 70 percent of the active pilots handling ships on the Sacramento Channel were recorded during the testing, it was decided that the statistical analysis could be based on parameter means rather than concentration on individual runs. The statistical analysis is presented for the three areas A, B, and C as the track plots were. Bar charts comparing the mean of means and standard deviation of the means for the three plans were analyzed for each parameter. The significant results are presented in the following paragraphs. Generally, a smaller standard deviation (i.e., less variation in the parameter) means less maneuvering was required and better control was available. Such a generalization cannot be made about the mean because the results are parameter dependent; e.g., higher clearance is desirable but less rudder is desirable.

Minimum clearances

41. One way to consider clearance is to look at the minimum values rather than the mean values. When the mean of the minimums is calculated, including groundings becomes a problem. Clearances are recorded as the closest distance from any point on the ship to the boundary of the channel. A negative distance signifies the ship passed the boundary. This usually indicates a grounding assuming the depths outside the boundary are less than the ship draft. Mean port and starboard minimum clearances for each run were obtained by averaging the minimum port and starboard clearances within each of the three areas.

42. Area A. Figure 25 shows that port minimum clearances dropped about 10 ft when current was present in Plan 0 (existing channel). For the proposed channel (Plan 1), port and starboard minimum clearances also dropped in tests with current. Starboard minimum clearances were about the same with or without current in Plan 0. Without current, the pilots seemed to get closer to the right side of the channel. They also did not get as close to the port

side in Plan 1 as they did in Plan 0. Generally, in this area, minimum port clearance was greater than starboard clearance. In the with-current case, the pilots tended to get closer to the starboard side in Plan 1 than they did in Plan 0. Overall, the minimum clearances show little difference between Plan 0 and Plan 1.

43. Area B. There is no difference between the with- or without-current cases for Plan 0 port minimum clearances (Figure 26). There was about a 5-ft decrease in the minimum port clearances with current in the Plan 1 results. The pilots tended to get closer to the port side with current, but not as much in this area as they did in area A. Minimum port clearances show about a 5-ft difference between Plans 0 and 1. No consistent differences can be seen between the with- and without-current cases for minimum starboard clearance. Generally, in this area, minimum port clearance was greater than starboard clearance. Figure 27 compares mean minimum port and starboard clearances for all three plans. For minimum starboard clearance there was little difference between Plans 0 and 1. For Plan 2, each side (port and starboard) has about 25 ft more clearance. This indicates that the pilots seemed to follow the same strategy despite the wider channel.

44. Area C. Figure 28 shows that the pilots got closer to the left side of the channel in the with-current cases as they had done in other areas. Port minimum clearance was less in the presence of the current in both Plans 0 and 1. The minimum starboard clearance shows no consistent difference between the with- and without-current cases. Generally the clearances for Plan 1 were slightly larger than for Plan 0.

45. Statistical analysis was also performed for the maximum port and starboard clearances, port clearances, and starboard clearances. The mean of mean and standard deviation for these parameters are included in Appendix C. The same basic results as discussed in the preceding paragraphs were obtained from these parameters.

Groundings

46. It is to be noted that a grounding in the simulator sense does not necessarily mean that a physical grounding would have occurred; rather, it means some part of the ship strayed beyond the boundary of the channel as defined in the simulator model. Only four groundings were recorded in the existing channel: one in area A, one in area B, and two in area C. They all occurred in the existing channel, under 20 knots of wind. The following

tabulation presents the number of runs with less than 20 ft of clearance (near-groundings) relative to the total number of runs made for that particular condition. In the existing channel there were many near-groundings with the majority of those occurring with the combined wind and current condition. The number of near-groundings in Plan 1 was slightly less than with the existing conditions for the tests with no wind. Limited testing of wind conditions with Plan 1 showed that the deeper draft of the ships significantly reduced the effects of wind on the ship; and due to the limited testing time available, further testing of Plan 1 with wind and currents was not required.

	Plan 0			Plan 1	
Area	No Current No Wind	With Current No Wind	With Current With Wind	No Current No Wind	With Current No Wind
A	1/10	1/12	4/10	0	0
B	0	0	2/10	0	1/10
C	0	0	4/10	0	0

Rudder angle

47. The preferable rudder angle setting is very definite: less rudder action is better.

48. Area A. Mean rudder angle and mean standard deviation are presented in Figure 29. The standard deviation values show about 12- to 15-deg variation. A large variation of rudder indicates that the pilot was switching the rudder back and forth with large magnitudes on either side of center. Figure 29 shows that in the no-current case, the mean of the rudder movements in this area was practically 0. This indicates that the pilots used bank forces to negotiate the 90-deg bend, using the rudder in a back-and-forth manner only to control. The use of bank forces to assist in tracking the angle is also indicated by the track plots. Rudder means increased negatively when current was present in both Plans 0 and 1. More variance for the with-current case was also recorded. Negative rudder, which should turn the ship to the right, was used in these cases when the pilot tried to make this turn. The turn is to the left; apparently, the current and bank forces made the ship have an overall moment to the left. To counteract this, the pilots had to use the right rudder to control the swing. There was no significant difference in mean rudder angle between Plans 0 and 1. About the same amount of variation was observed in Plans 0 and 1.

49. Area B. When current was present, a little more rudder was used in

both Plans 0 and 1 (Figure 30). Again, the magnitude of rudder use as shown by the standard deviation is about the same in Plans 0 and 1, although a small increase in the variation of the rudder is shown for Plan 1 in the presence of current. The mean rudder angles also indicate no significant difference between Plans 0 and 1. Figure 31 compares rudder usage between plans. The standard deviation of rudder use was less for Plan 1 than for Plan 0 and even less in Plan 2.

50. Area C. The mean rudder used was less with currents than without currents (Figure 32). Apparently, the current helped the ship to maneuver around this lower turn. In the without-current case, less variation was recorded in Plan 1 than in Plan 0. A little more variation is shown in the with-current case for Plan 1. This results from a high reading on one particular run. For some unexplained reason, the pilot changed rudder more; this may indicate that he used kick turns. Overall the mean rudder used to make the turn in the Plan 1 channel was larger than that used in Plan 0. This could explain why there was more clearance on the port side in Plan 1 than in Plan 0 as noted in the section, "Minimum clearances."

Revolutions per minute

51. Area A. The rpm decreased with current in Plan 0 (Figure 33). About the same rpm was used with or without currents in Plan 1. Less variation can be seen with currents in Plan 0. More variation is observed with current effects included in Plan 1. Plan 1 shows less variance than Plan 0 in all cases. Engine control was steadier in Plan 1.

52. Area B. Less rpm was recorded with currents in both Plans 0 and 1 because the currents probably assisted in moving the ship (Figure 34). The standard deviation was higher in the with-current case, particularly in Plan 1. This was caused by one run in which the pilot appeared to be in trouble. The pilot increased his rpm and used a kick turn to get the ship under control again. It also was caused by another run in which the pilot constantly increased rpm, constantly speeding up. Without these two runs, the standard deviation would be about the same as the without-current case. There is not much difference in mean rpm between all plans (Figure 35). The difference between Plan 1 and Plan 2 is about 10 rpm. All the pilots seemed to run faster in Plan 2. This could be due to a feeling of increased comfort in the deeper and wider channel. Standard deviation was fairly high in Plan 2. This is due to one run in which the pilot kept changing the rpm. Without this

particular run, the standard deviation would be about 1.5 rpm. It should be noted that even the higher standard deviation does not exceed 10 percent of the mean rpm.

53. Area C. With Plan 0, higher rpm was recorded with current effects, but less deviation was observed in this area (Figure 36). The rpm was about the same in Plan 1 with or without currents. The standard deviation for the case with currents in Plan 1 was high. This explains why more rudder variation is evident in area C. Without current, rpm did not vary as much in Plan 1 as in Plan 0. Generally, there was not much difference between Plans 0 and 1.

Drift angle

54. The drift angle is the angle of motion from the heading of a ship. Pilots call this condition "set." It usually is on the order of 1-2 deg either port or starboard. Set typically occurs when a ship is not traveling parallel to the current, or it can be caused by high winds or "sliding" of the ship.

55. Area A. A small drift angle was recorded for Plans 0 and 1 (Figure 37). The difference was about 0.1 to 0.3 deg. Tests of Plan 0 with current show a little more drifting. The standard deviation shows little difference between the with- and the without-current cases.

56. Area B. In this area, the drift angle recorded was about the same with all conditions (Figure 38). The standard deviation is slightly larger in the with-current case. Less drift angle deviation was recorded for Plan 2 than for Plans 1 and 0 (Figure 39). Plan 1 had the largest average drift angle, about -0.1 deg.

57. Area C. Larger drift angle was recorded with current in both Plans 0 and 1 because the currents probably pushed the ship to the side (Figure 40). However, the difference was less than 0.3 deg. More variation was observed with current effects included in both Plans 0 and 1. Plan 1 showed less variance than Plan 0 in all cases.

Rate of turn

58. The rate of turn is a measure of how fast the ship is rotating about its center of gravity. Considering the huge mass of a ship, the pilots attempt to keep the rate of turn to a minimum to avoid momentum getting out of control.

59. Area A. More rate of turn was observed with current in both

Plans 0 and 1, probably because the current tended to push the ship to the opposite side (Figure 41). More deviation was also recorded with current in both plans. Plan 1 showed less variance than Plan 0 in all cases.

60. Area B. The standard deviation showed about 2 to 3 deg of variation (Figure 42). A smaller rate of turn was recorded with current in Plan 0, but no difference was evident in the with- or without-current cases in Plan 1. The standard deviation was high in the with-current case, particularly in Plan 1. This was caused by one run in which the pilot appeared to be in trouble. His rate of turn was constantly changing to get the ship under control. Without this run the standard deviation would be the same as the without-current case. Mean rate of turn and standard deviation were decreased in the proposed channels (Plans 1 and 2, Figure 43). About the same standard deviation was observed in Plans 1 and 2.

61. Area C. Mean rate of turn showed no difference between with- and without-current cases (Figure 44). More variation can be seen with current in both Plans 0 and 1. The difference is about 2.5 deg. Plan 1 had less variation than Plan 0.

Heading

62. Area A. The mean heading and standard deviation are presented in Figure 45. The average value was approximately 225 deg. The same heading was observed in both plans for all cases. There was not much difference in the mean standard deviation either.

63. Area B. Again, the mean heading was the same in both plans for all cases (Figure 46). Less variation occurred in Plan 0 with currents. More variation was observed with current effects included in Plan 1. Less variation was recorded for Plan 2 (Figure 47). The average heading was about the same for all three plans (0, 1, and 2). No conclusion can be drawn on the basis of the variability of heading.

64. Area C. No significant difference was recorded between Plans 0 and 1 (Figure 48).

Speed

65. Speed seems to be more pilot dependent than channel dependent. As a result, no conclusions can be drawn concerning the effect of the proposed channel. At the beginning of the tests, each pilot was asked to maintain a realistic speed while conning the simulator. According to the pilots, they

usually maintain a speed between 5 and 7 knots while transiting the ship channel.

66. Area A. Mean speed as shown in Figure 49 indicates that the pilots seemed to go faster when current was present in both Plans 0 and 1. More variation is observed with current effects included in Plan 1.

67. Area B. Again, the speed was increased with the current included (Figure 50). More variation was also recorded. Figure 51 indicates that the same average speed was maintained in all the channels (Plans 0, 1, and 2). More variation was recorded in Plan 2. This could result from the pilots' feeling more comfortable in the bigger channel as well as less bank effect from the higher speed in the large channel.

68. Area C. The average speed was increased with the with-current condition in both Plans 0 and 1 (Figure 52). More variation was recorded with the current included in Plan 0

PART IV: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

69. The test results of the Sacramento Deepwater Ship Channel Simulator Study, Phase I, reveal these conclusions:

- a. There is little difference between navigation of ships in the existing channel and in the proposed channel (deepened without widening in the straight reaches). Slightly but consistently better control is evident in the proposed channel (Plan 1). The design ship 610 ft long and 93 ft wide should have no more problem in Plan 1 than it has in the existing channel.
- b. Currents do make some difference in the navigation requirements. Generally, there was less clearance between the ship and banks with currents present than in slack-water conditions, probably due to trimming of the ship. This result is supported by the increased rudder that was used in most of areas A and B as defined by Figure 5.
- c. Larger bank clearances were evident with the 50-ft widening in Plan 2. Also, control of the ship appeared to be easier. Plan 2 would definitely provide more allowance for error, drift, and wind effects on the ships.
- d. For the large ships, the 855-ft bulk carrier, no definitive conclusion can be drawn since the hydrodynamic model of the ship was not validated for these conditions and only a small sampling of the pilots was tested.

Recommendations

70. It is recommended that when the Sacramento Deepwater Ship Channel from mile 18.6 to the Sacramento Harbor is deepened by 5 ft (from 30 to 35 ft):

- a. The straight sections can remain 200 ft wide.
- b. The turns should be widened to 250 ft.

Table 1

Professional Pilot Testing Program

Outbound Transits

Test No.	Date	Run Code	Pilot	Plan	With or Without Current	With or Without Wind
01	02/24/88	BM1N	1	0	With current	No wind
02	02/24/88	AM2N5	2	0	No current	No wind
03	02/24/88	BM1N2	1	0	With current	No wind
04	02/24/88	EM2N	2	1	With current	No wind
05	02/24/88	CM1N2	1	0	With current	With wind
06	02/24/88	BM2N	2	0	With current	No wind
07	02/24/88	EM1N	1	1	With current	No wind
08	02/25/88	CM2N	2	0	With current	With wind
09	02/25/88	AM1N4	1	0	No current	No wind
10	02/25/88	DM2N	2	1	No current	No wind
11	02/25/88	DM1N	1	1	No current	No wind
12	02/25/88	EM2N2	2	1	With current	No wind
13	02/25/88	EM1N2	1	1	With current	No wind
14	02/15/88	BM2N2	2	0	With current	No wind
15	02/25/88	FM1N1	1	1	With current	With wind
16	03/01/88	AM3N2	3	0	No current	No wind
17	03/01/88	DM4N	4	1	No current	No wind
18	03/01/88	EM3N	3	1	With current	No wind
19	03/01/88	BM4N	4	0	With current	No wind
20	03/01/88	BM4N2	4	0	With current	No wind
21	03/01/88	CM3N	3	0	With current	With wind
22	03/02/88	CM4N	4	0	With current	With wind
23	03/02/88	BM3N	3	0	With current	No wind
24	03/02/88	AM4N2	4	0	No current	No wind
25	03/02/88	DM3N	3	1	No current	No wind
26	03/02/88	GM4N	4	2	No current	No wind
27	03/02/88	GM3N	3	2	No current	No wind
28	03/03/88	DM3N	3	1	No current	No wind
29	03/03/88	EM4N	4	1	With current	No wind
30	03/03/88	AM3N3	3	0	No current	No wind
31	03/03/88	BM4N3	4	0	With current	No wind
32	03/03/88	EM3N2	3	1	With current	No wind
33	03/03/88	DM4N2	4	1	With current	No wind
34	03/03/88	BM3N2	3	0	With current	No wind
35	03/03/88	AM4N3	4	0	No current	No wind

(Continued)

Note: All tests conducted with 610- by 93-ft ship except those marked by asterisk. These were conducted with 855- by 106-ft ship.

Table 1 (Concluded)

Test No.	Date	Run Code	Pilot	Plan	With or Without Current	With or Without Wind
36	03/04/88	EM4N2	4	1	With current	No wind
37	03/04/88	GM3N2	3	2	No current	No wind
38	03/04/88	GM4N2	3	2	No current	No wind
39*	03/04/88	GL3N	3	2	No current	No wind
40*	03/04/88	GL4N	4	2	No current	No wind
41	03/04/88	CM3N2	3	0	With current	With wind
42	03/04/88	CM4N2	4	0	With current	With wind
43	03/08/88	DM5N	5	1	With current	No wind
44	03/08/88	EM6N	6	1	With current	No wind
45	03/08/88	BM5N	5	0	With current	No wind
46	03/08/88	AM6N3	6	0	No current	No wind
47	03/09/88	EM5N	5	1	With current	No wind
48	03/09/88	DM6N	6	1	No current	No wind
49	03/09/88	GM5N	5	2	No current	No wind
50	03/09/88	GM6N	6	2	No current	No wind
51	03/09/88	CM5N	5	0	With current	With wind
52	03/09/88	CM5N	6	0	With current	With wind
53	03/09/88	AM5N2	5	0	No current	No wind
54	03/09/88	BM6N	6	0	With current	No wind
55	03/10/88	DM6N2	5	1	No current	No wind
56	03/10/88	EM6N2	6	1	With current	No wind
57	03/10/88	AM5N3	5	0	No current	No wind
58	03/10/88	BM6N2	6	0	With current	No wind
59	03/10/88	GM5N2	5	2	No current	No wind
60	03/10/88	GM6N2	6	2	No current	No wind
61	03/10/88	EM5N2	5	1	With current	No wind
62	03/10/88	DM6N2	6	1	No current	No wind
63	03/11/88	BM5N2	5	0	With current	No wind
64	03/11/88	AM6N4	6	0	No current	No wind
65	03/11/88	CM5N2	5	0	With current	With wind
66	03/11/88	CM6N2	6	0	With current	With wind
67*	03/11/88	GL5N	5	2	No current	No wind
68*	03/11/88	GL5N2	5	2	No current	No wind
69*	03/11/88	DL6N	6	1	No current	No wind
70*	03/11/88	DL5N2	5	1	No current	No wind

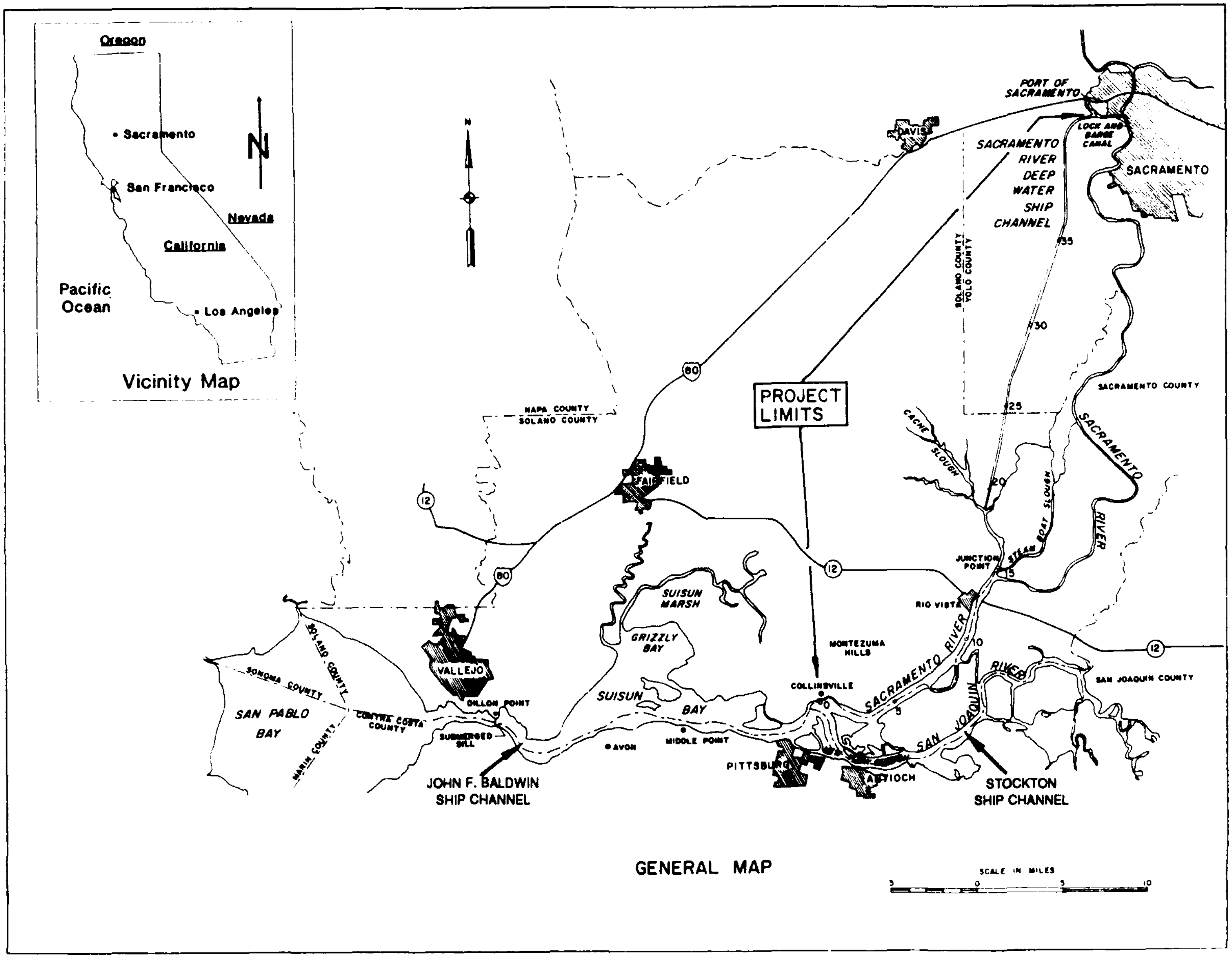


Figure 1. Project location, Sacramento River Deepwater Ship Channel

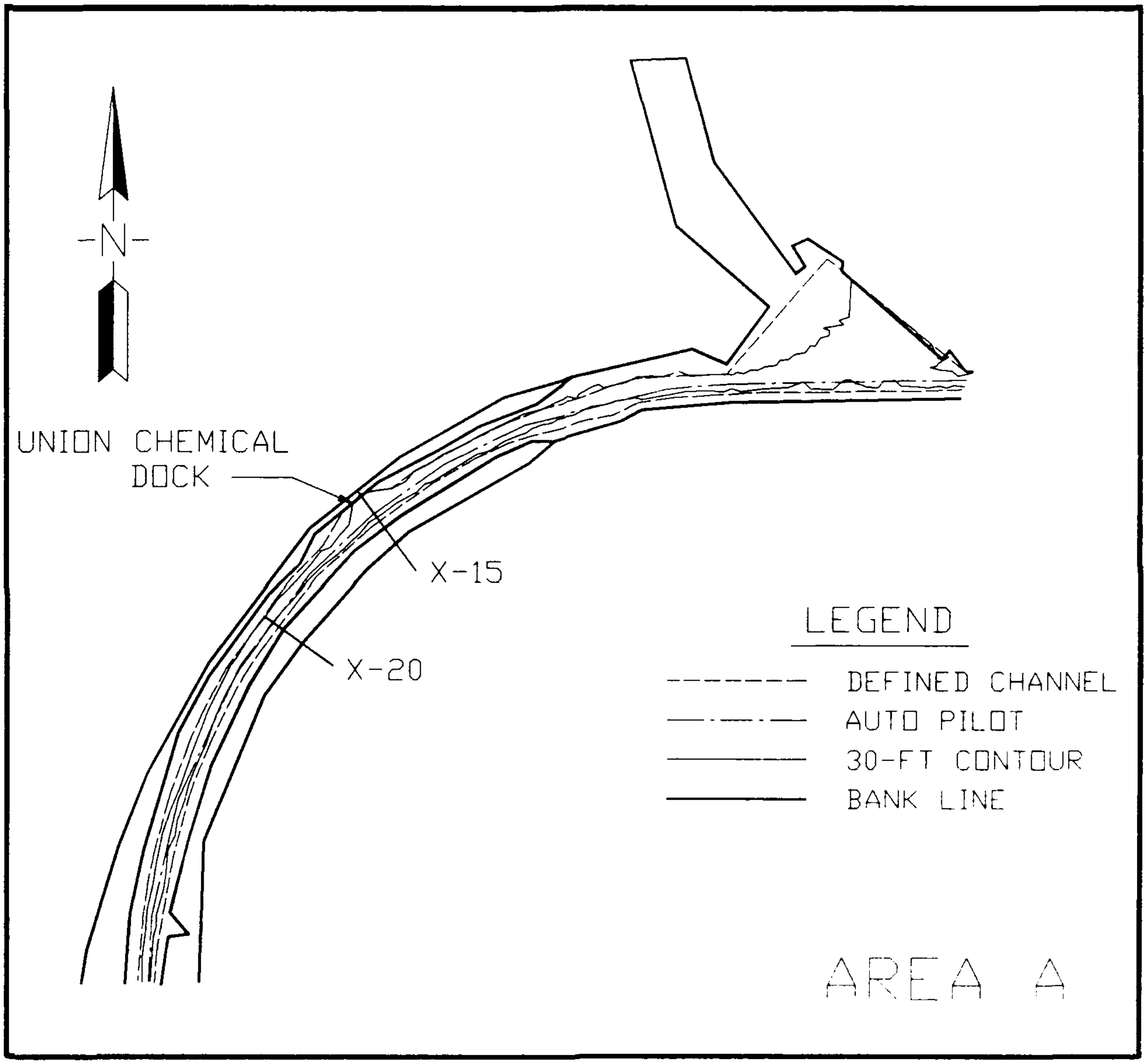


Figure 2. Channel definition for ship simulation study, area A

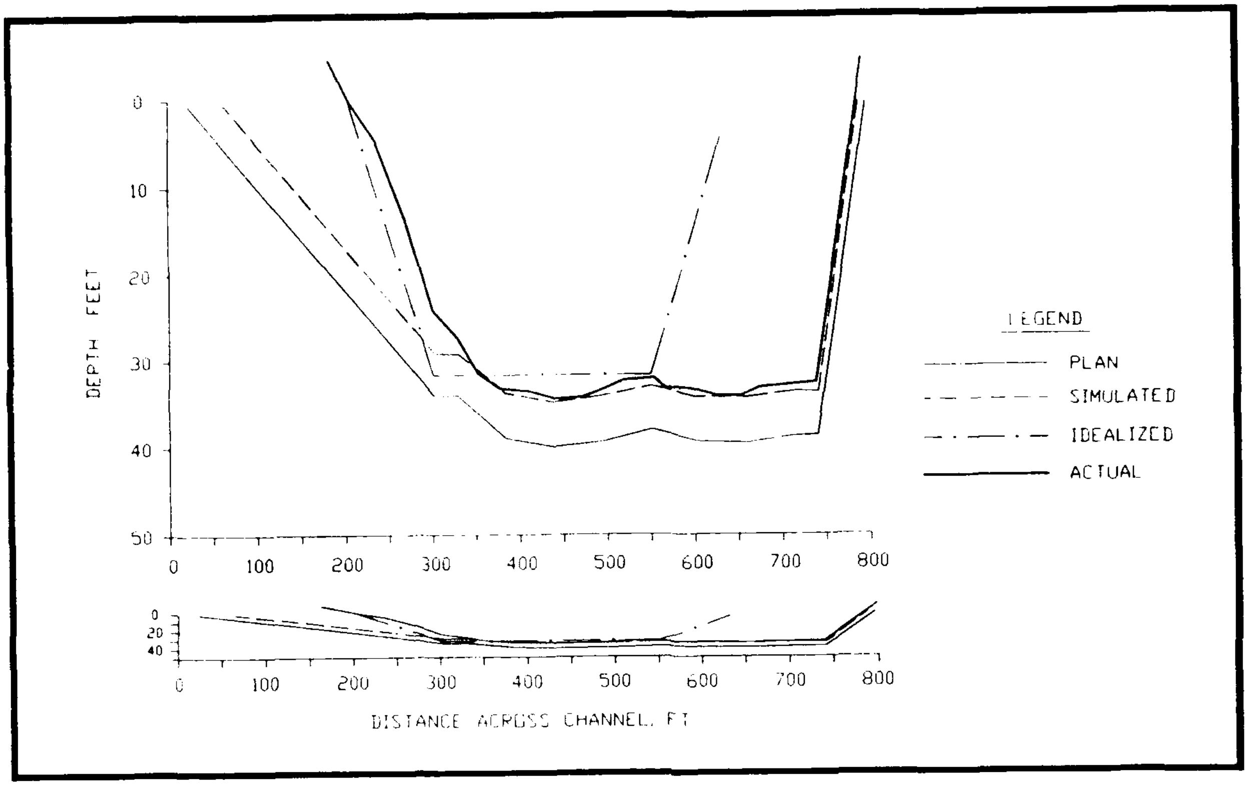


Figure 3. Existing and modeled channel, cross-section 15

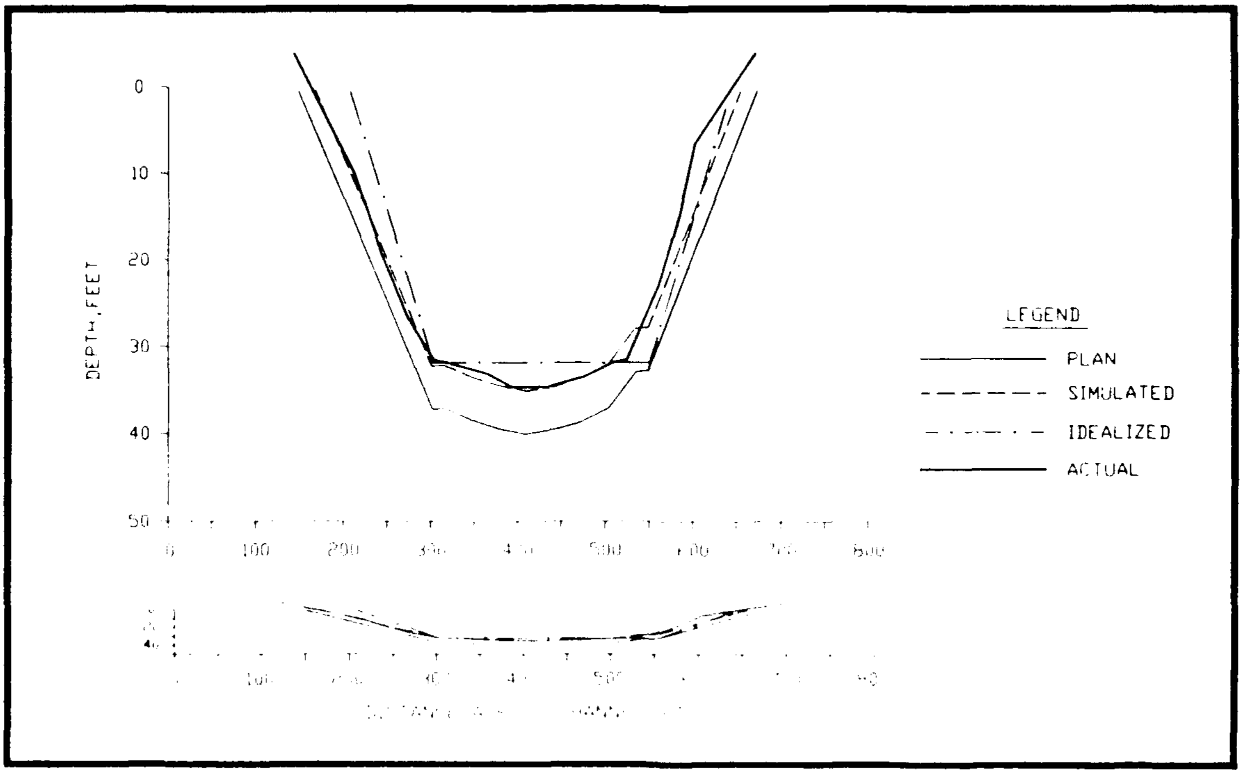


Figure 4. Existing and modeled channel, cross-section 20

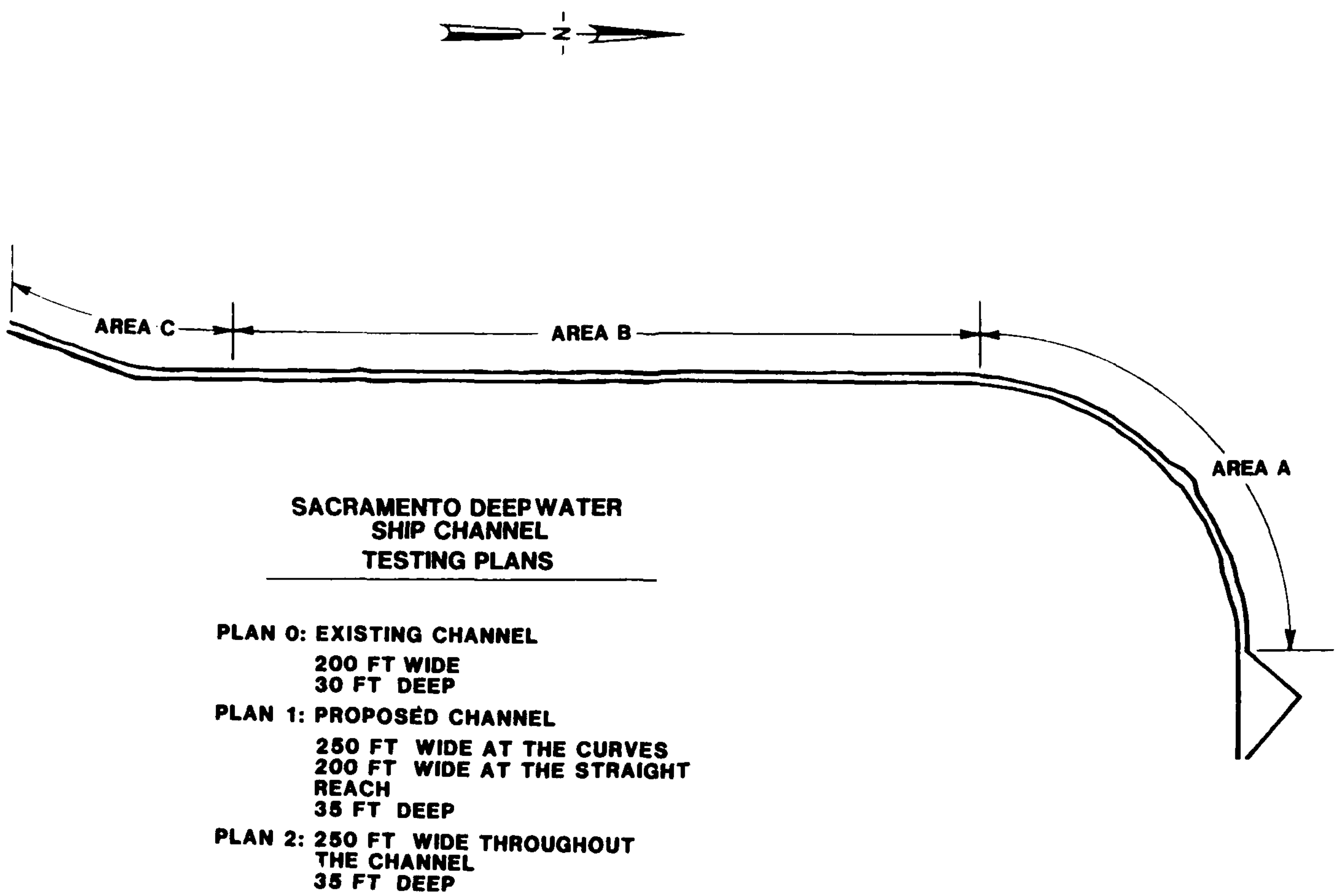


Figure 5. Sacramento Deepwater Ship Channel test area and plan definitions

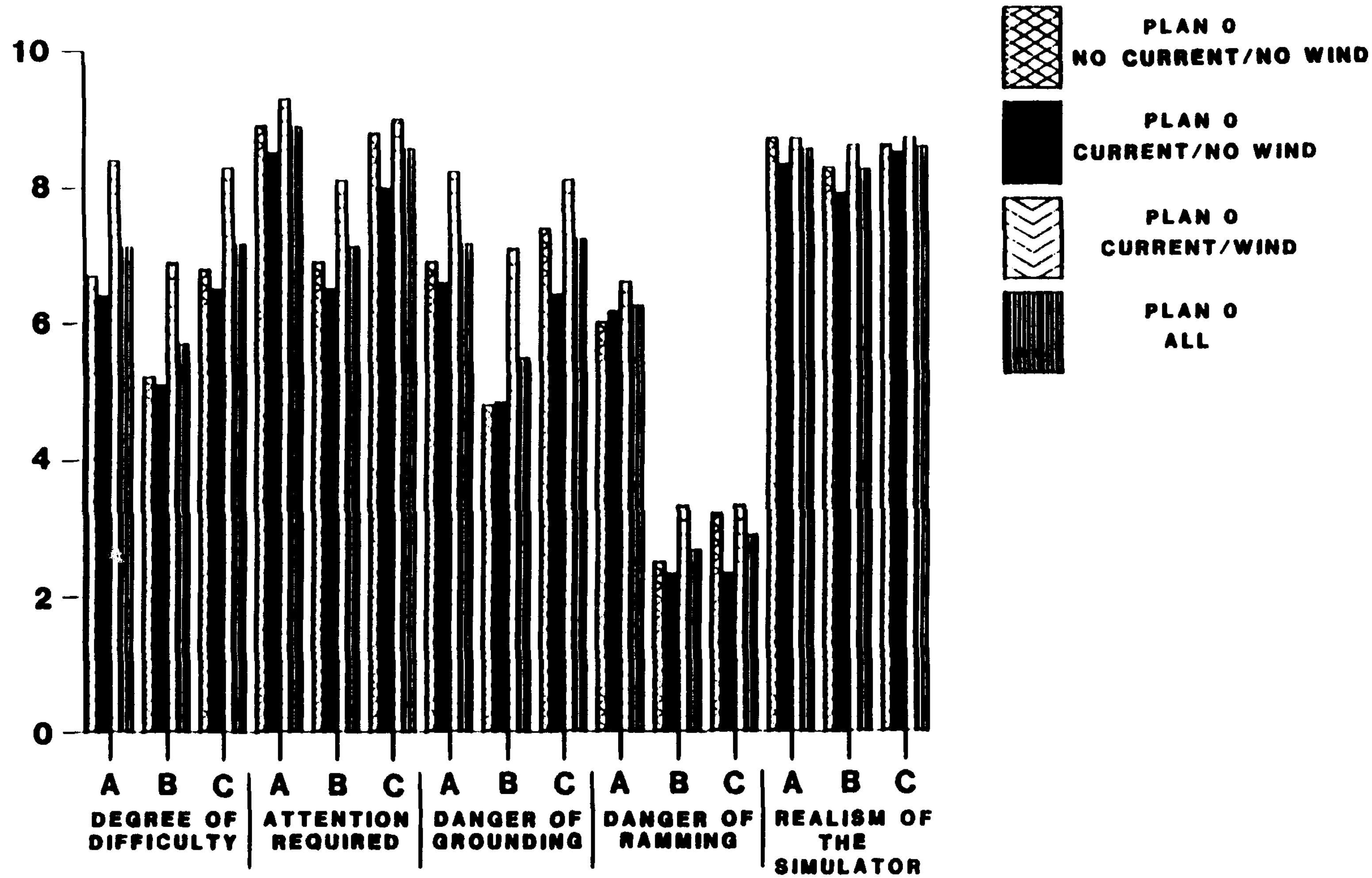


Figure 6. Pilots' ratings, Plan 0

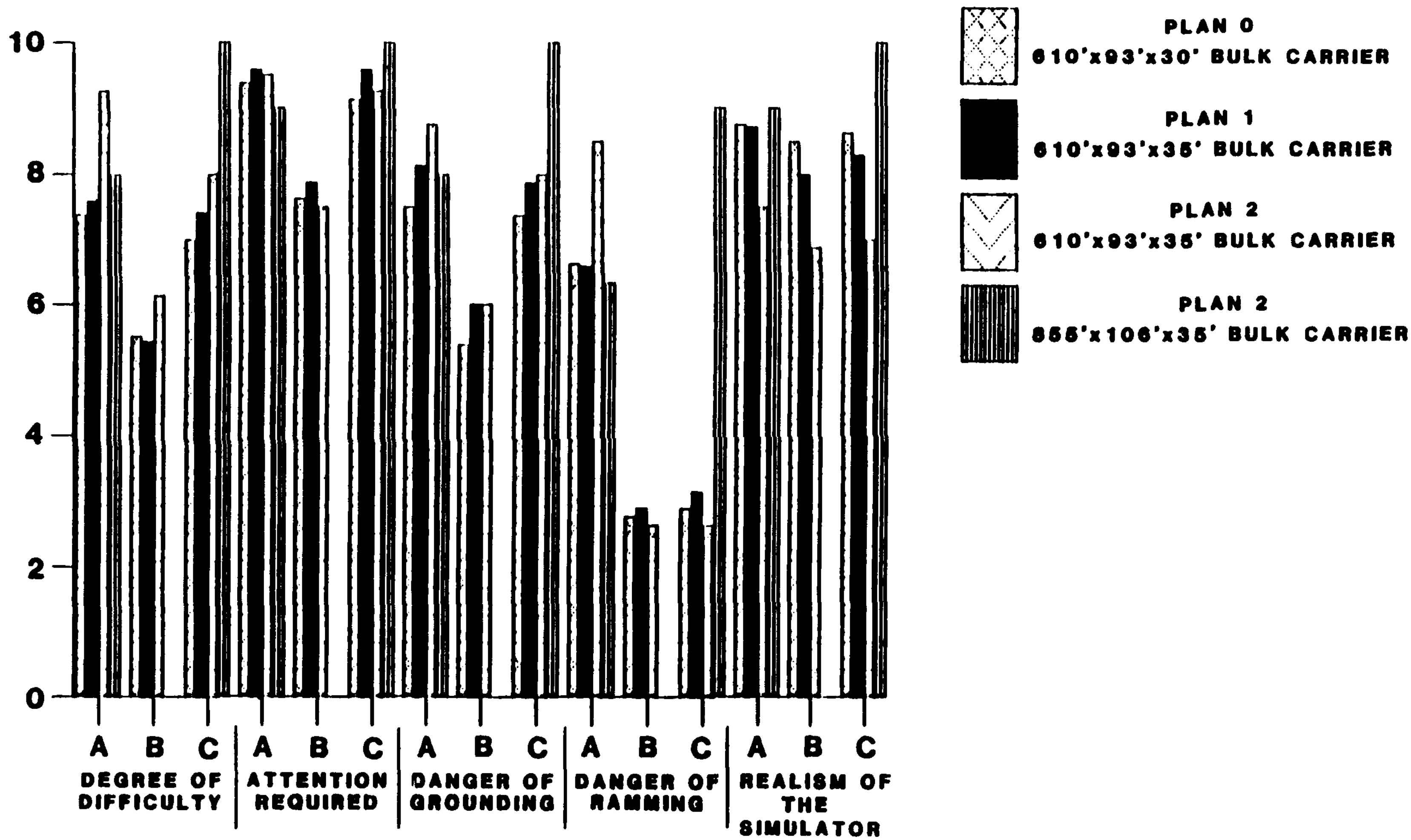


Figure 7. Comparison of pilots' ratings for plans with no wind and no current

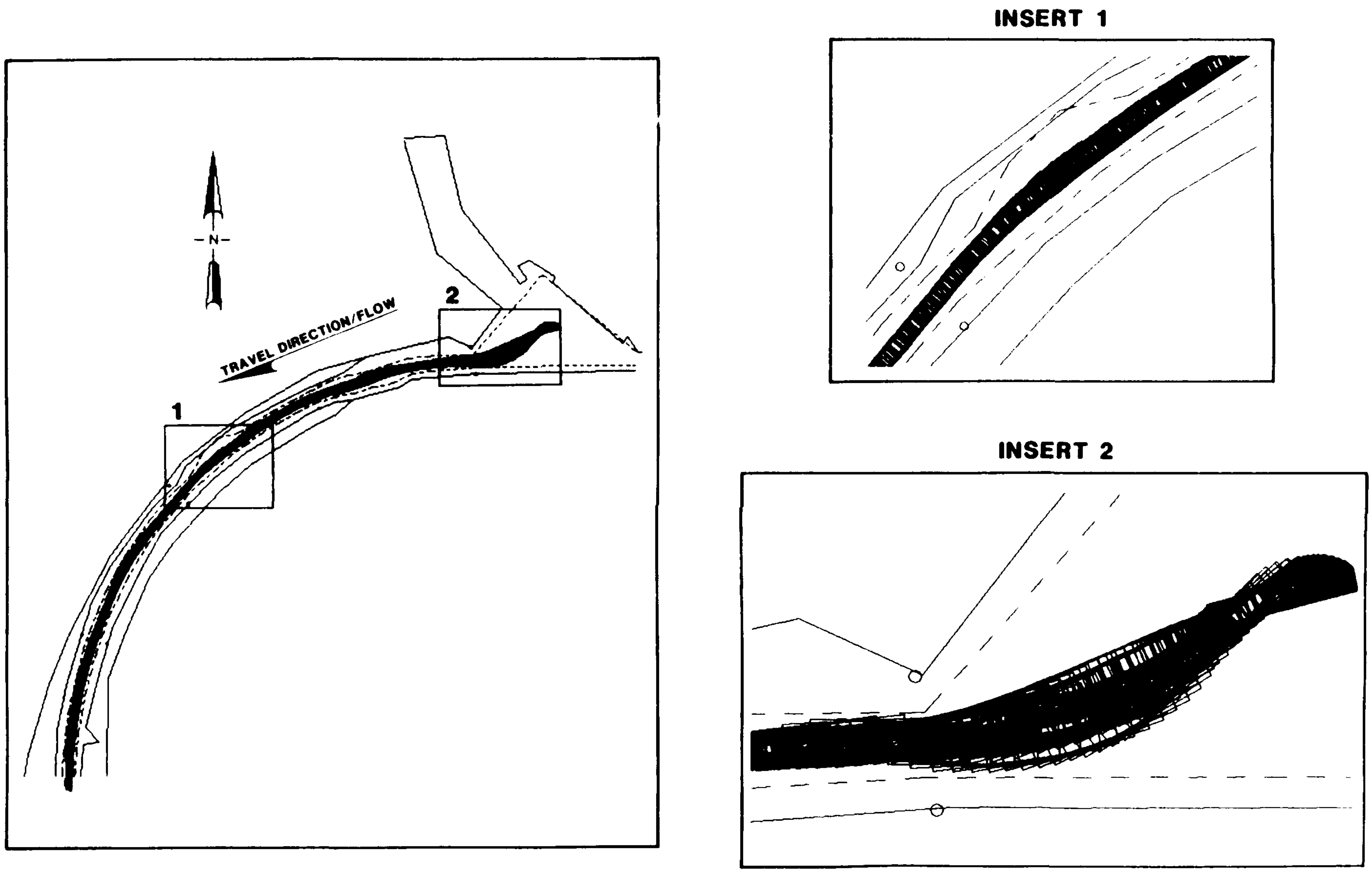


Figure 8. Ship track plots for Plan 0 in area A, no current and no wind

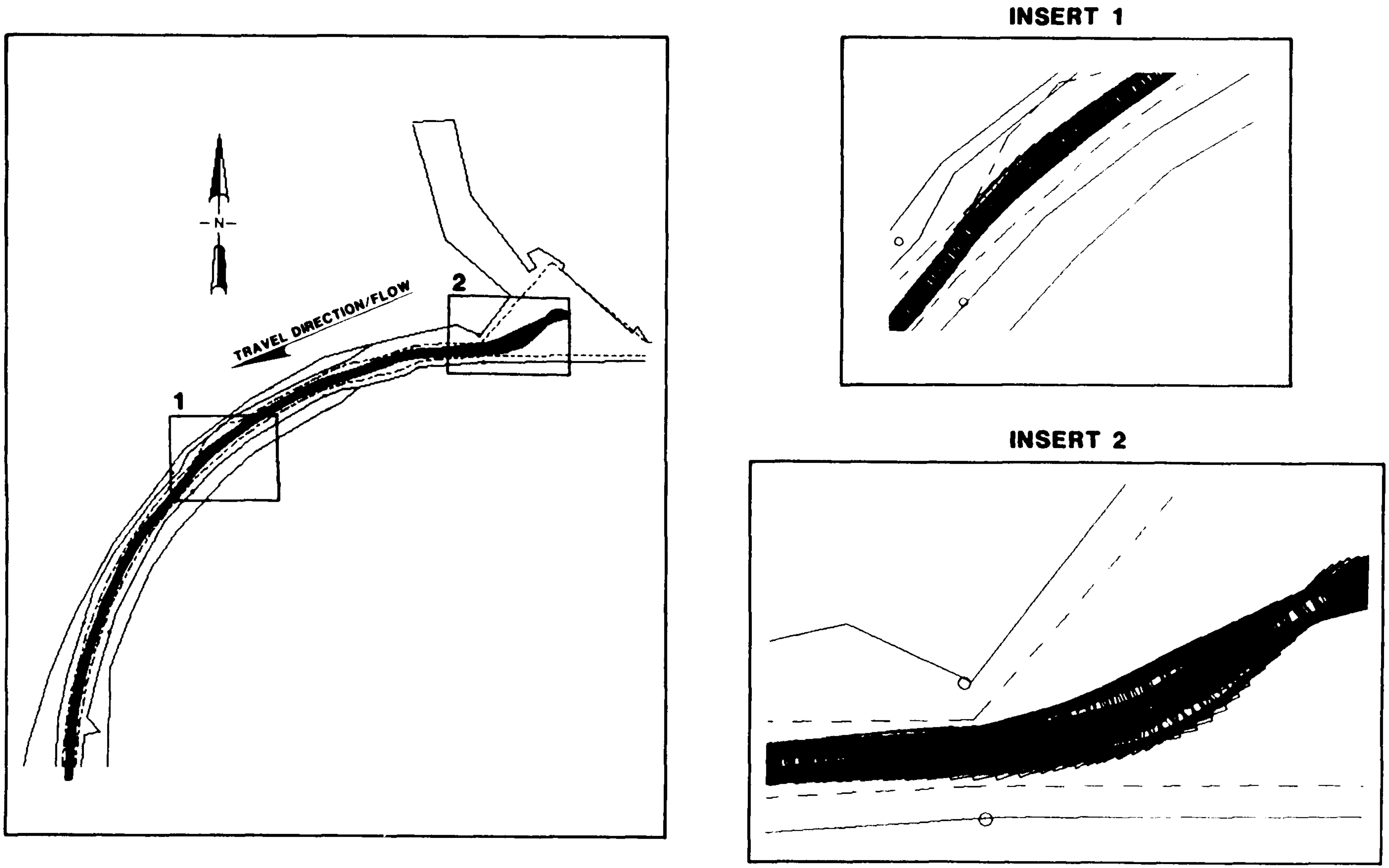


Figure 9. Ship track plots for Plan 0 in area A, with current and no wind

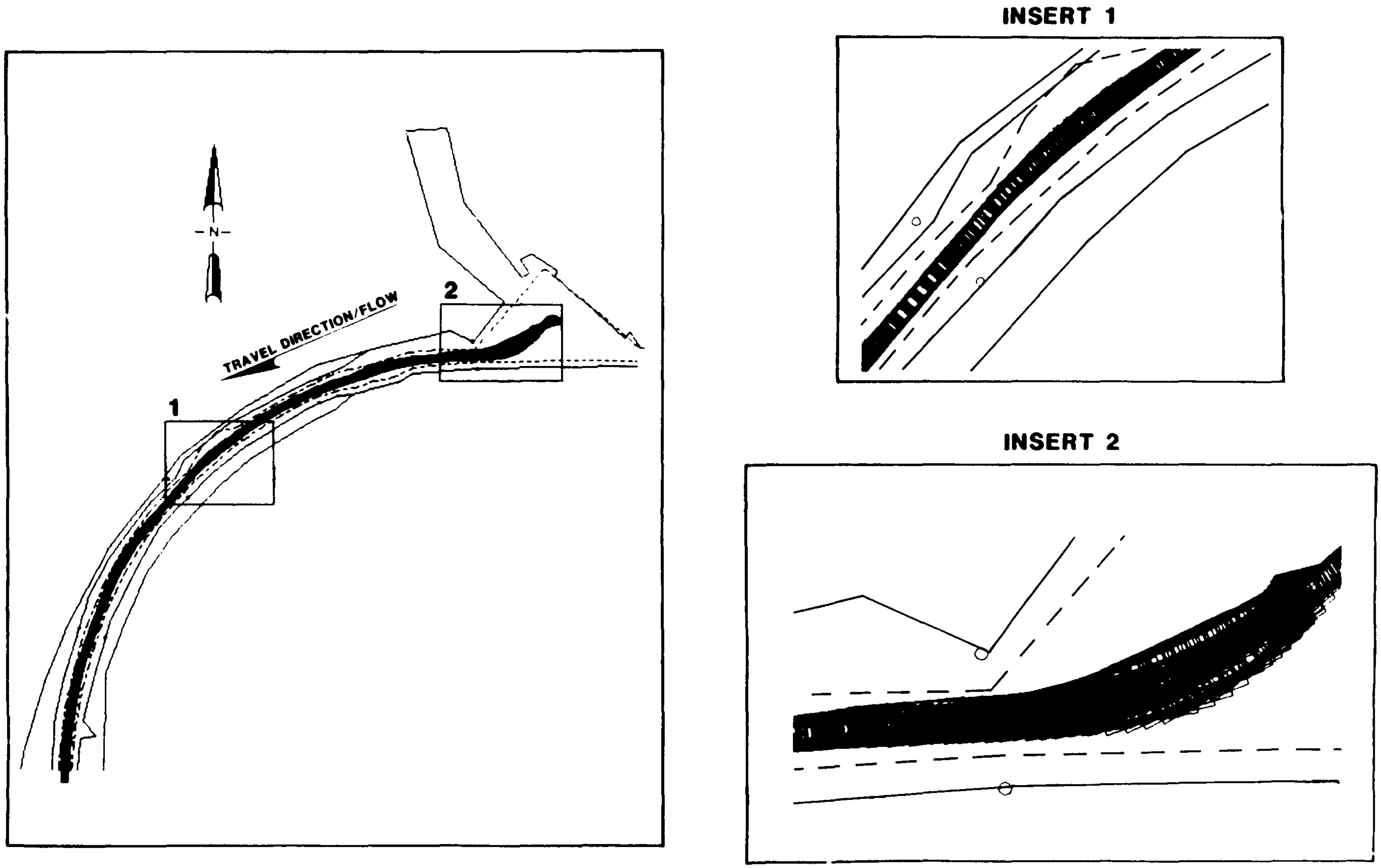


Figure 10. Ship track plots for Plan 1 in area A, no current and no wind

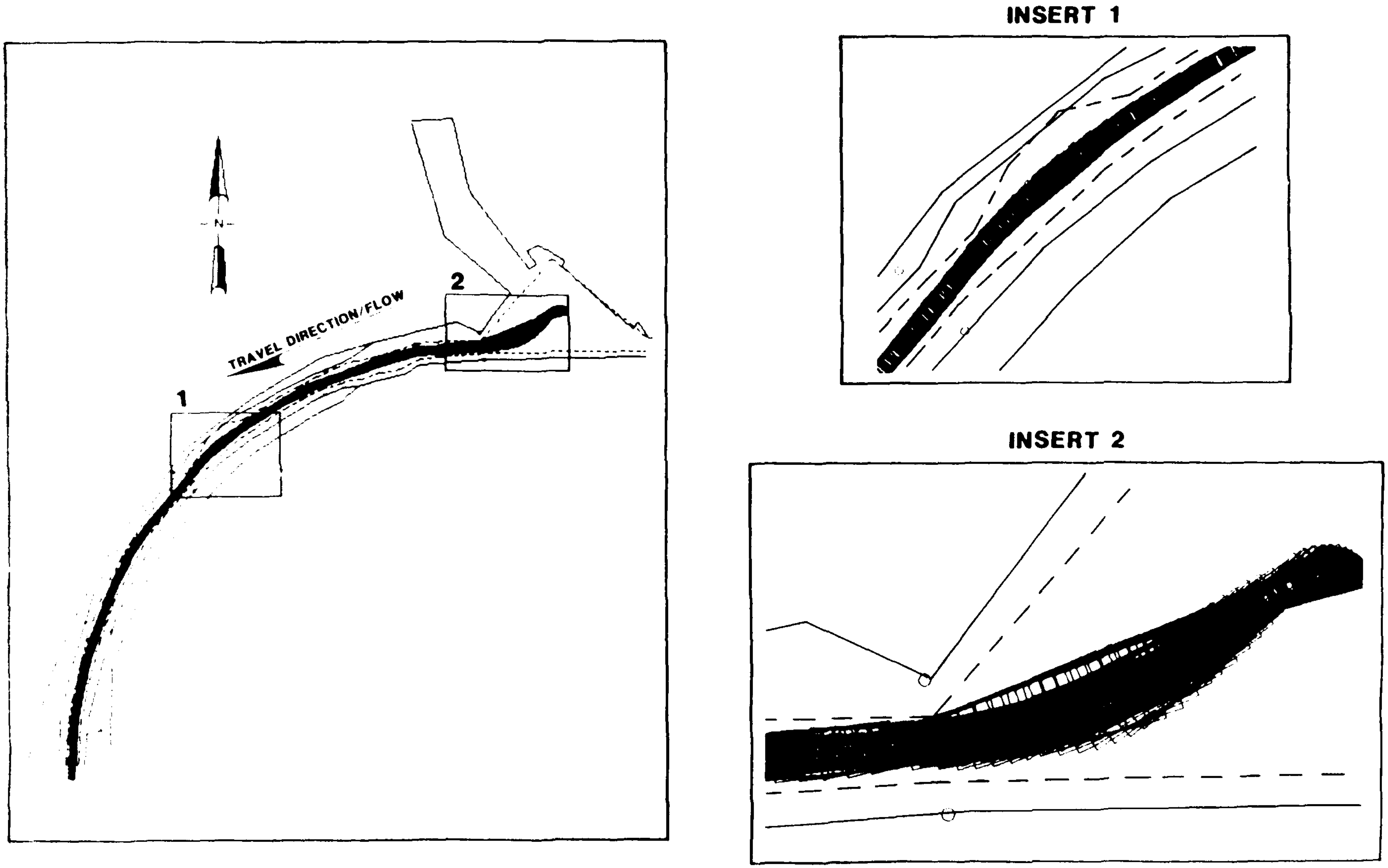


Figure 11. Ship track plots for Plan 1 for area A, with current and no wind

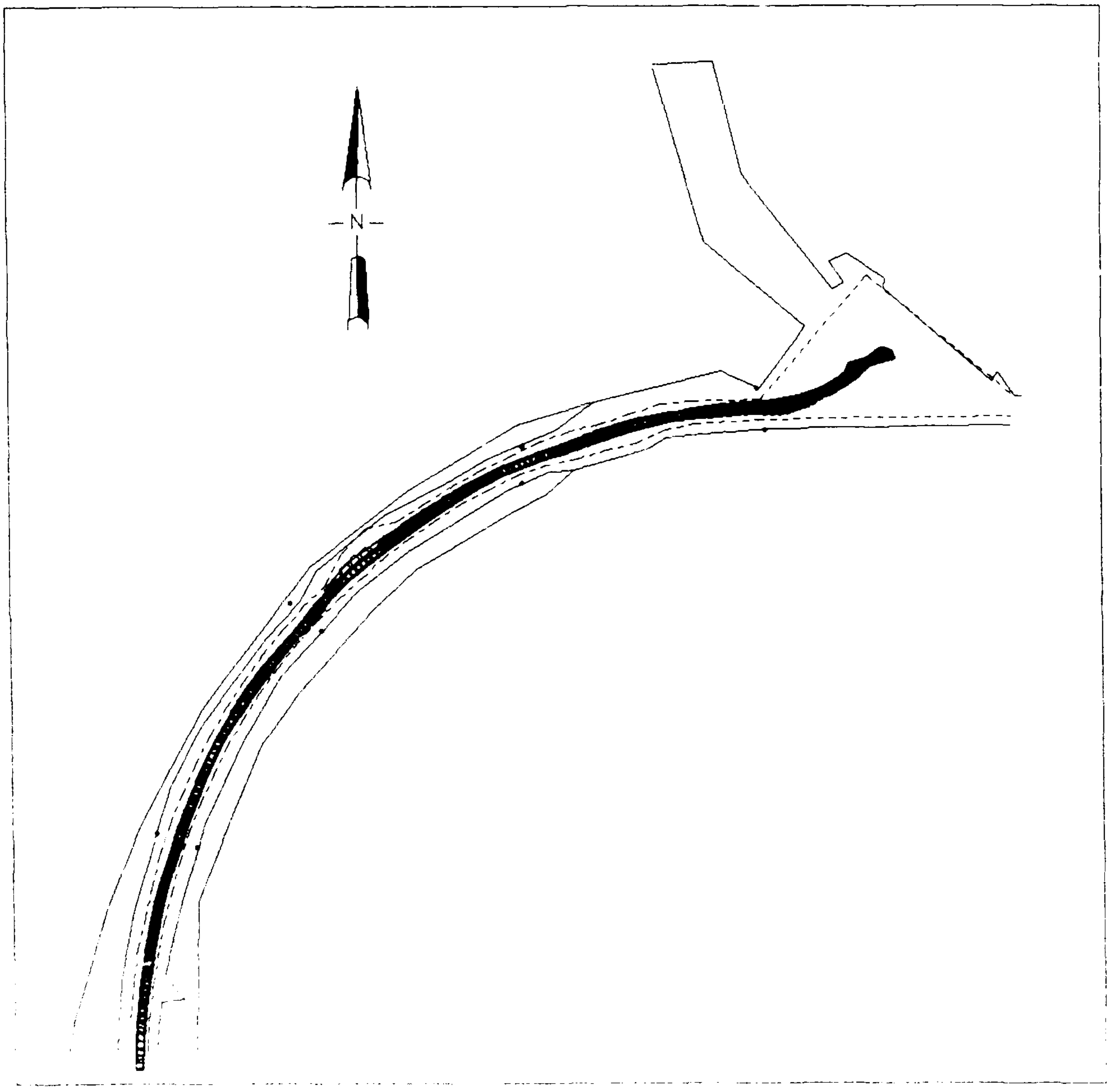


Figure 12. Ship track plots for Plan 2 for area A, no current and no wind, 610-ft ship

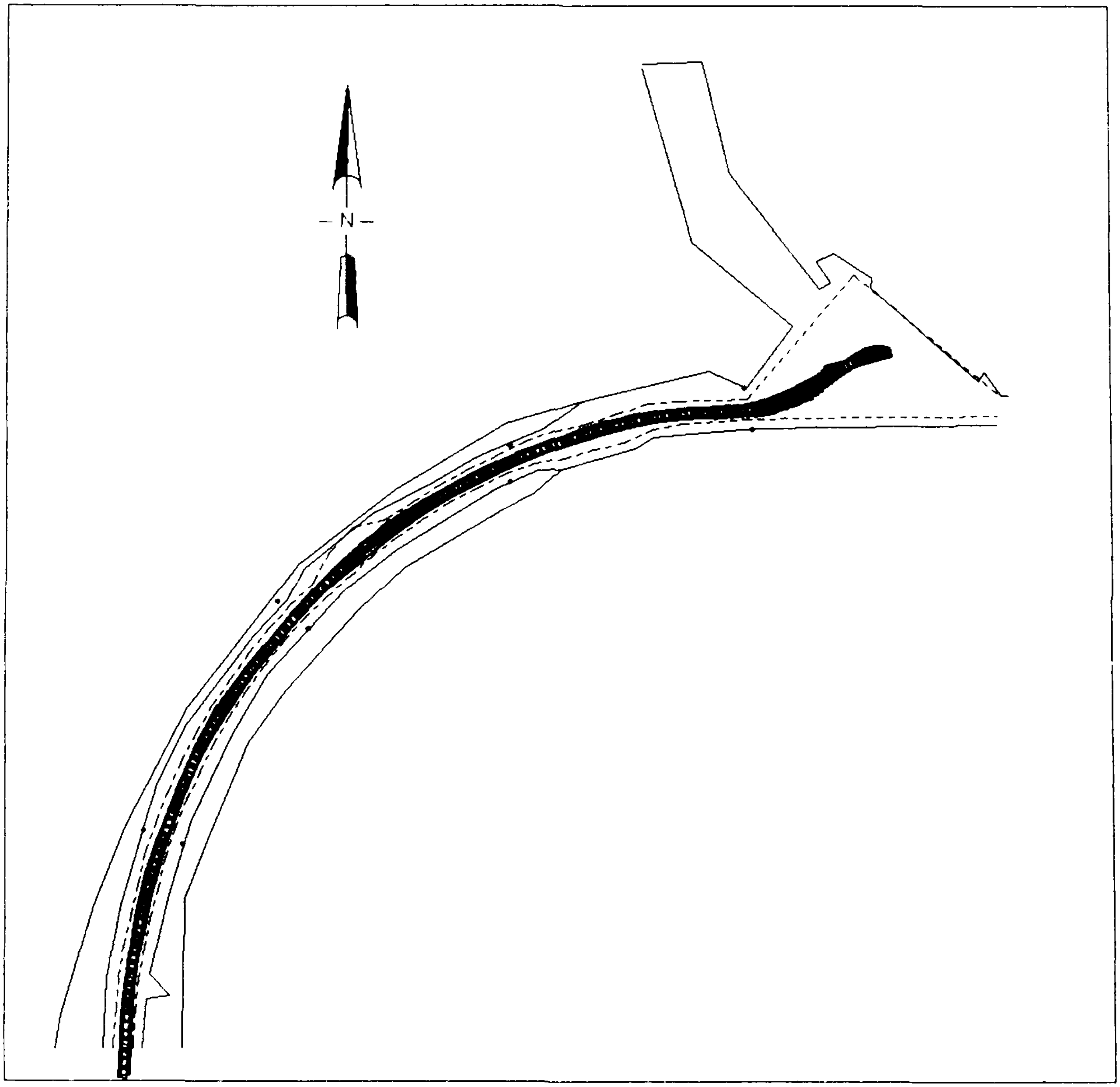


Figure 13. Ship track plots for Plan 2 for area A, no current and no wind, 855-ft ship

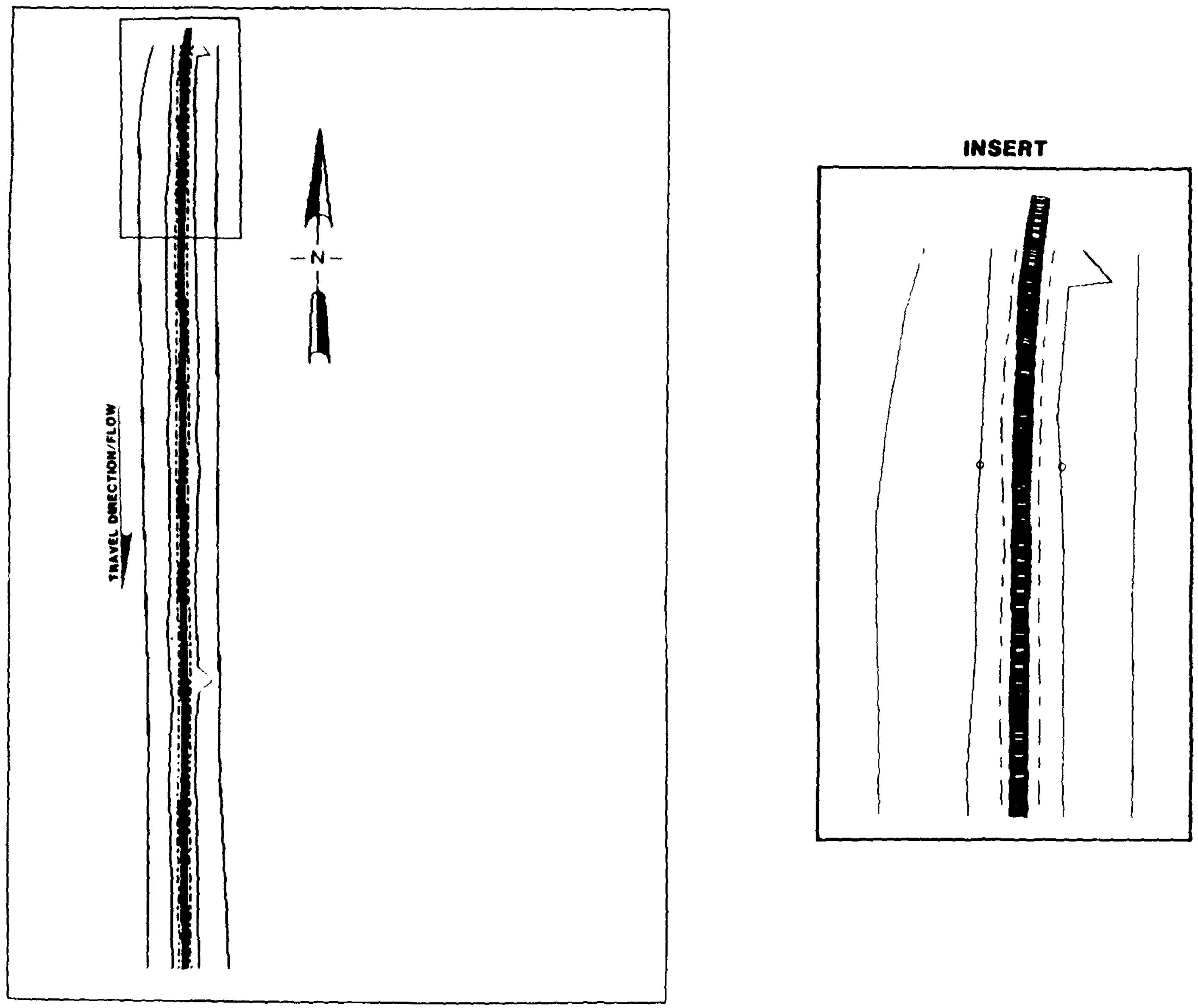


Figure 14. Ship track plots for Plan 0 for area B, no current and no wind

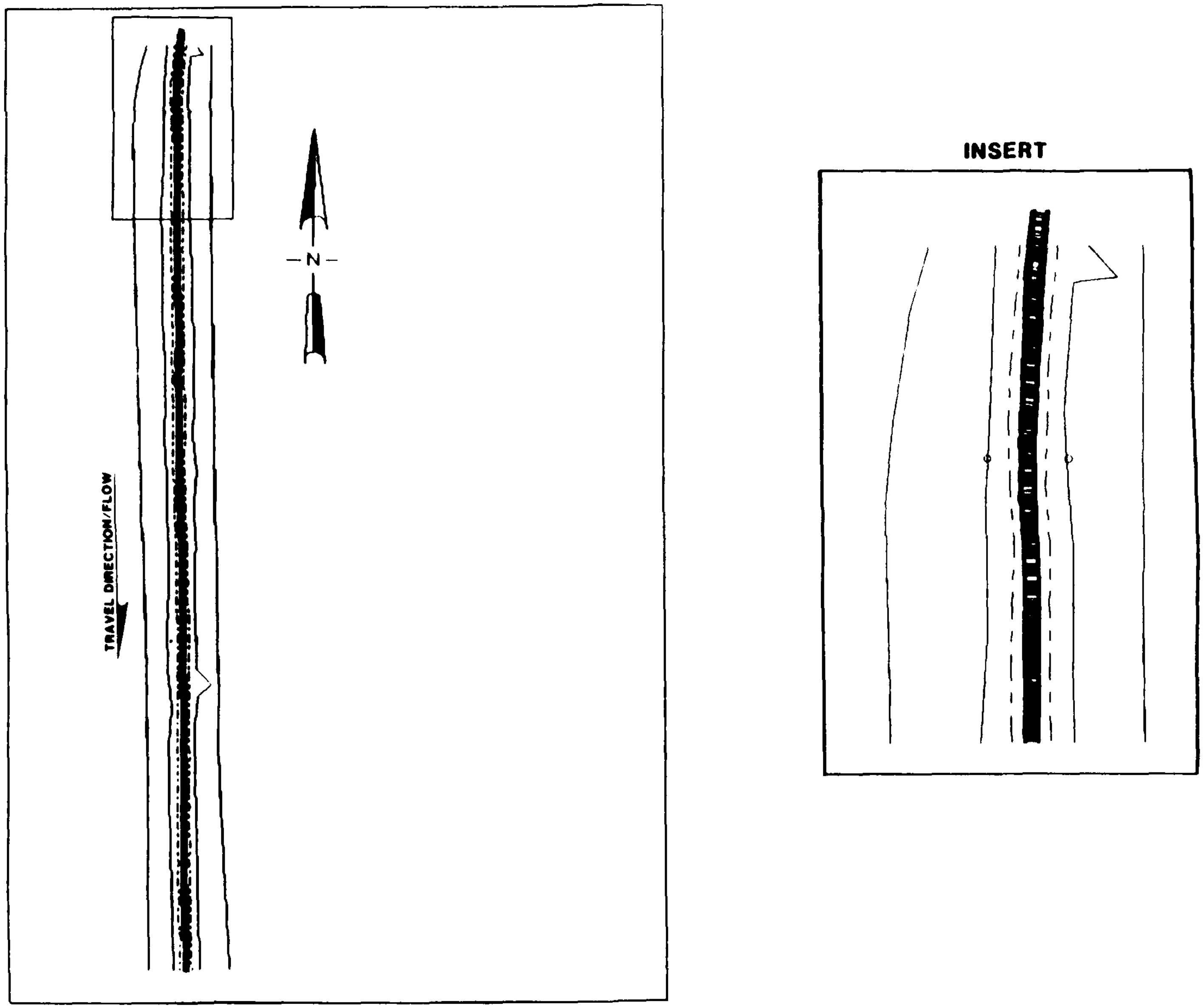


Figure 15. Ship track plots for Plan 0 for area B, with current and no wind

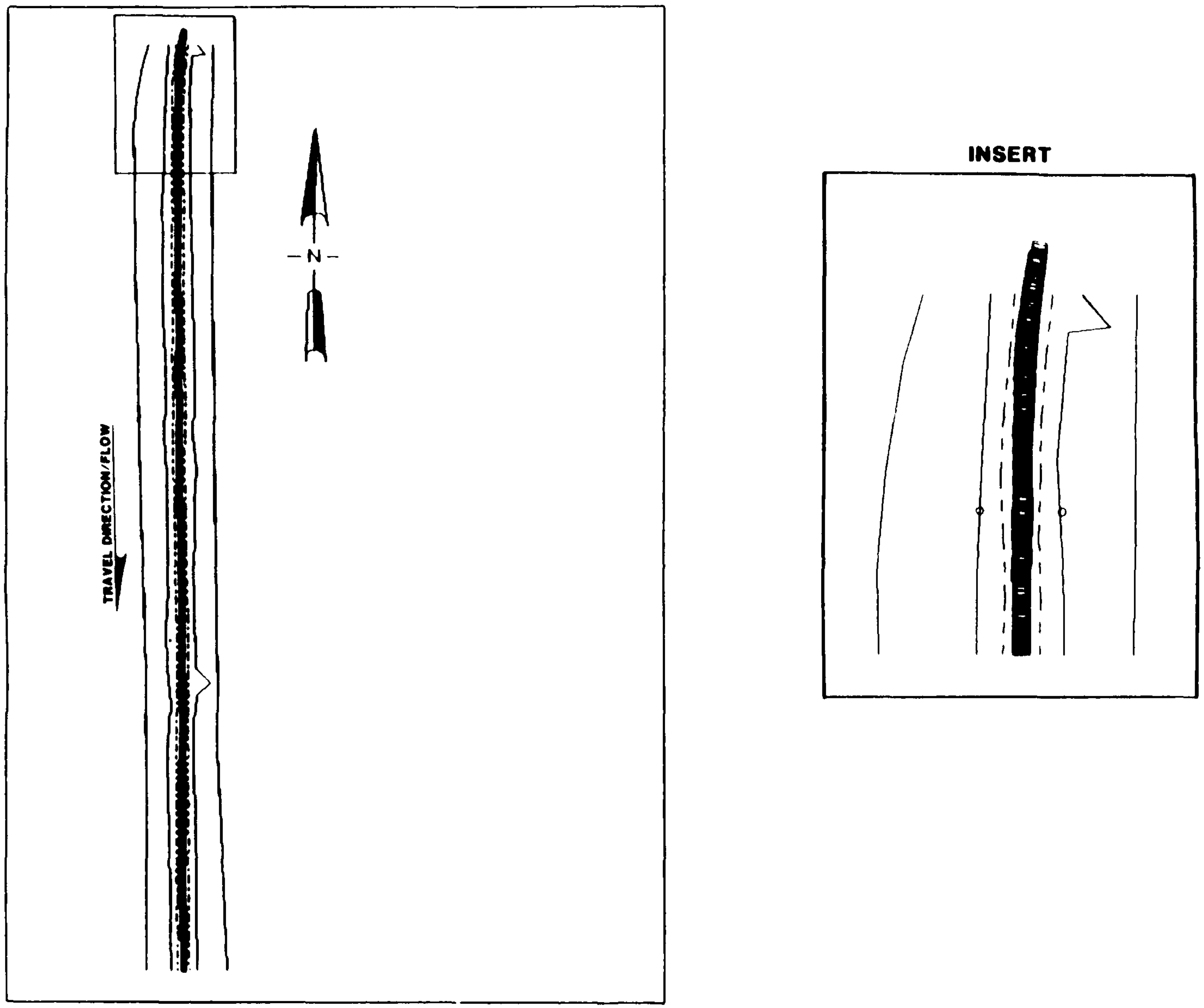


Figure 16. Ship track plots for Plan 1 for area B, no current and no wind

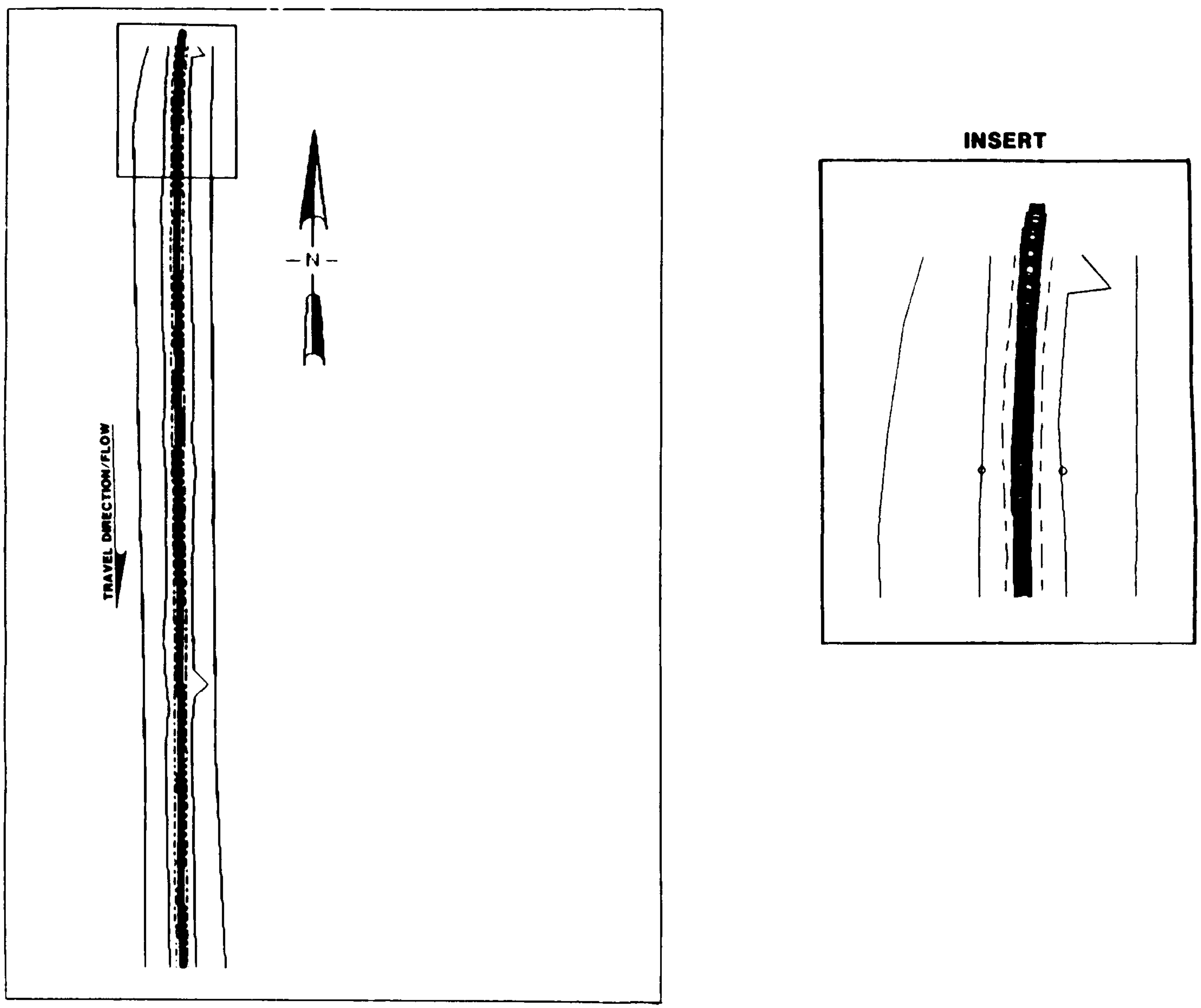


Figure 17. Ship track plots for Plan 1 for area B, with current and no wind

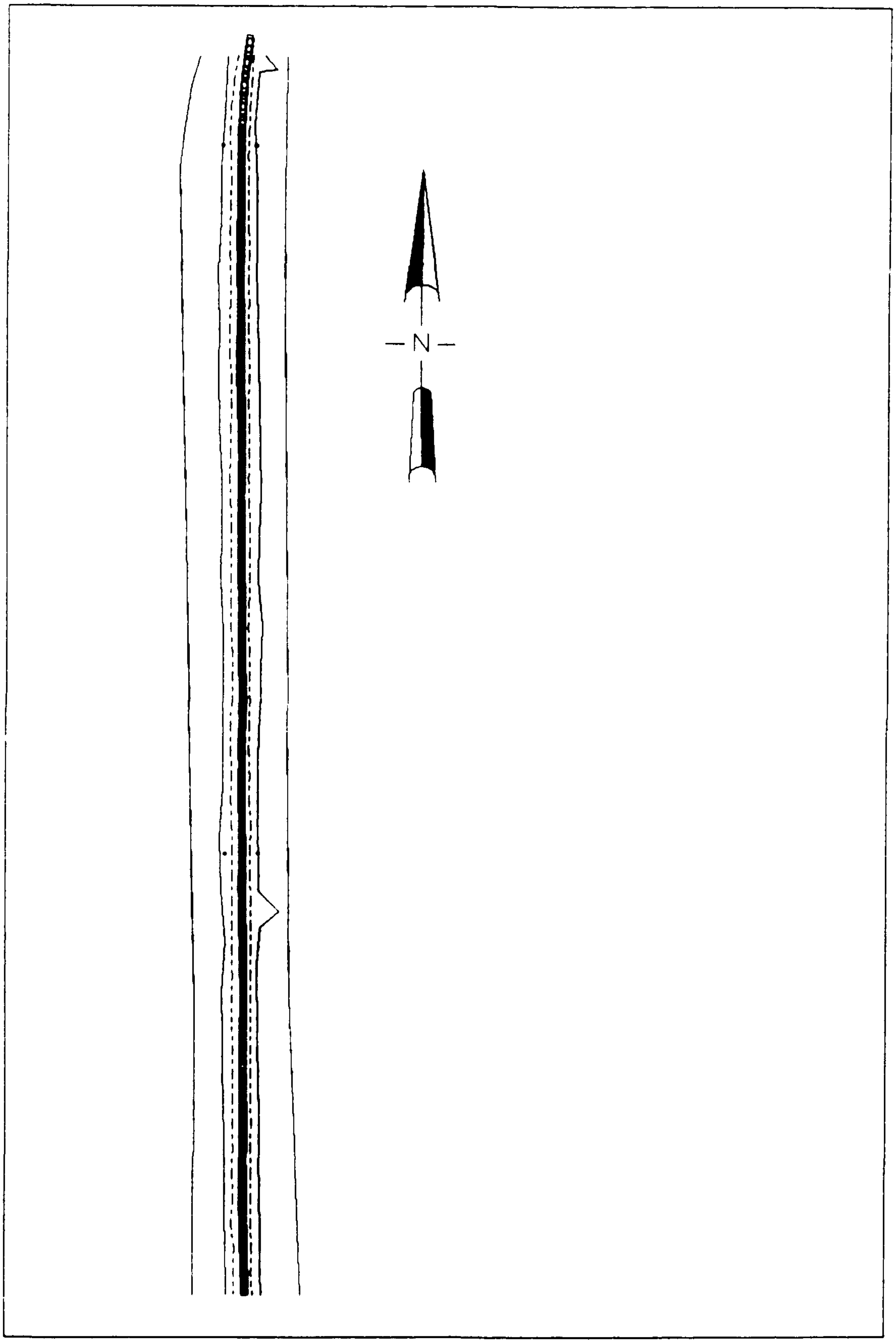


Figure 18. Ship track plots for Plan 2 for area B, no current and no wind, 610-ft ship

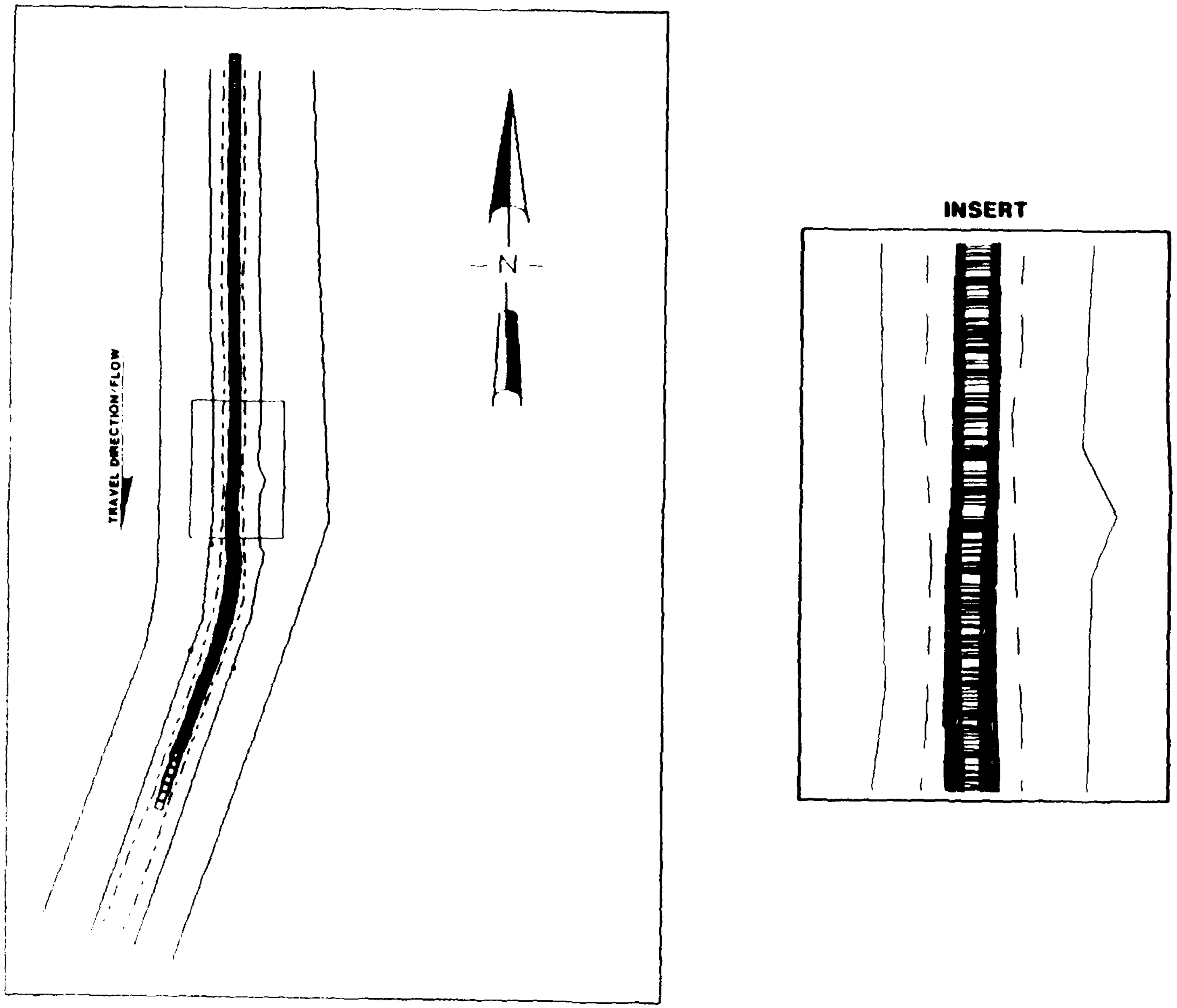


Figure 19. Ship track plots for Plan 0 for area C, no current and no wind

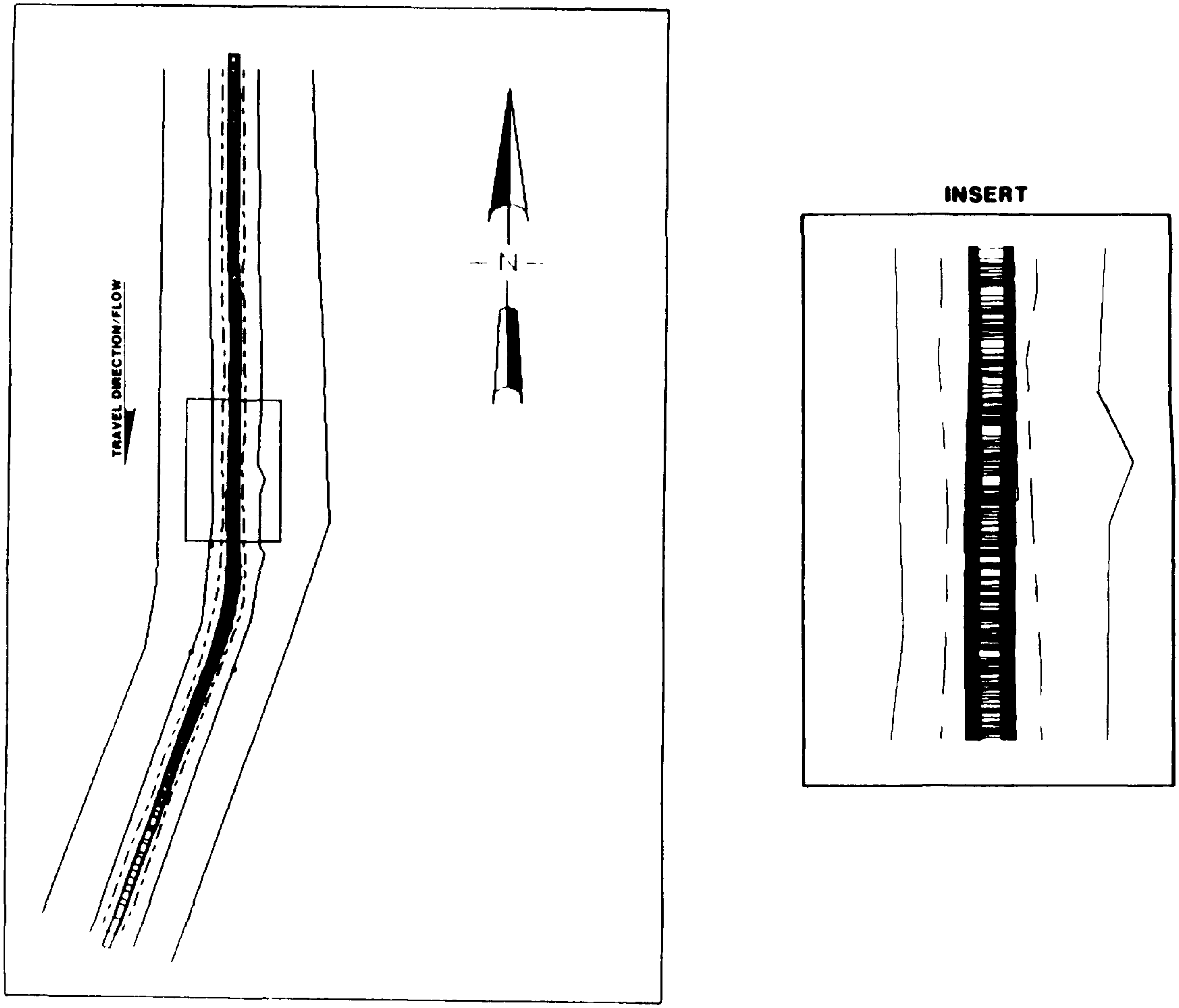


Figure 20. Ship track plots for Plan 0 for area C, with current and no wind

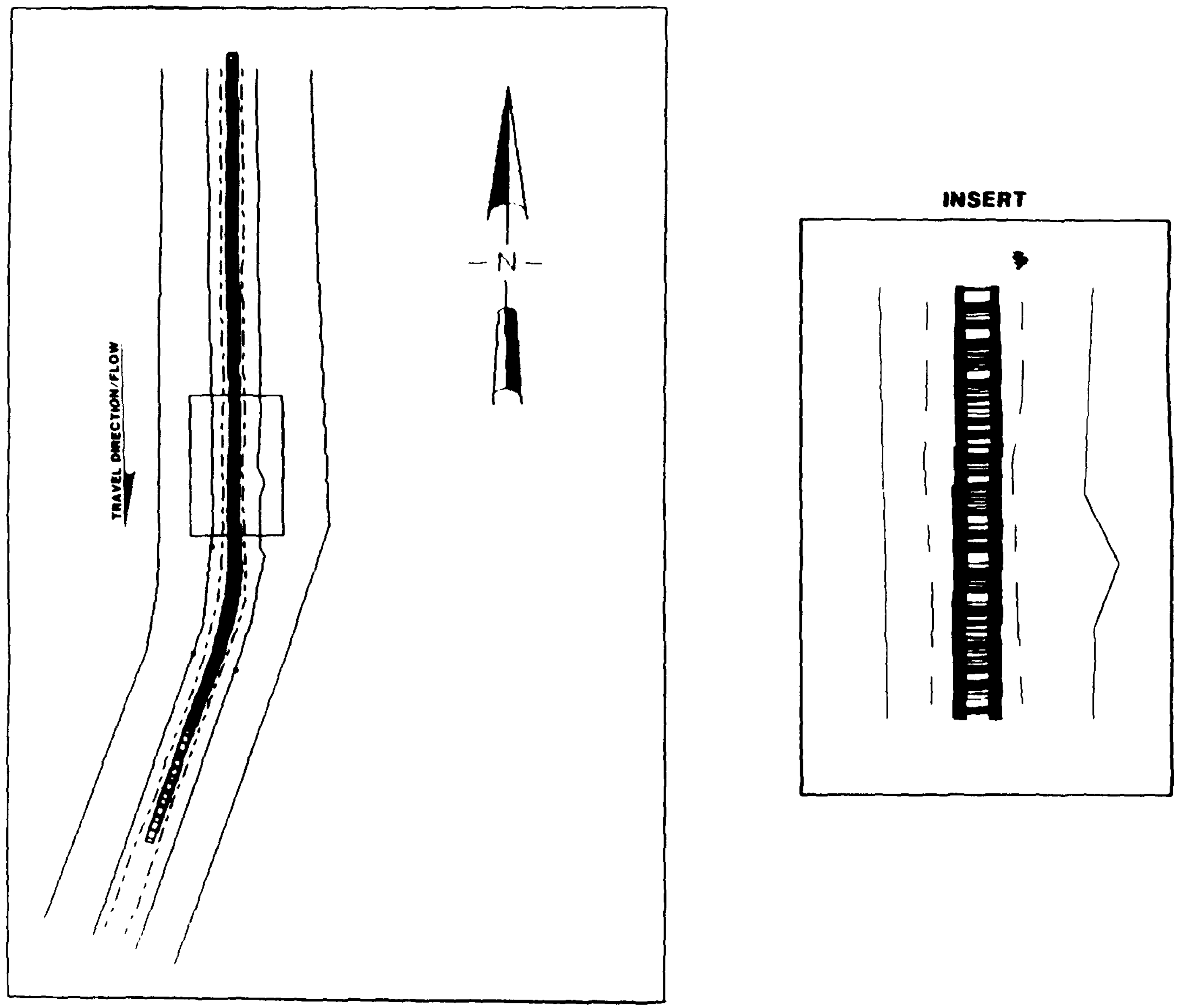


Figure 21. Ship track plots for Plan 1 for area C, no current and no wind

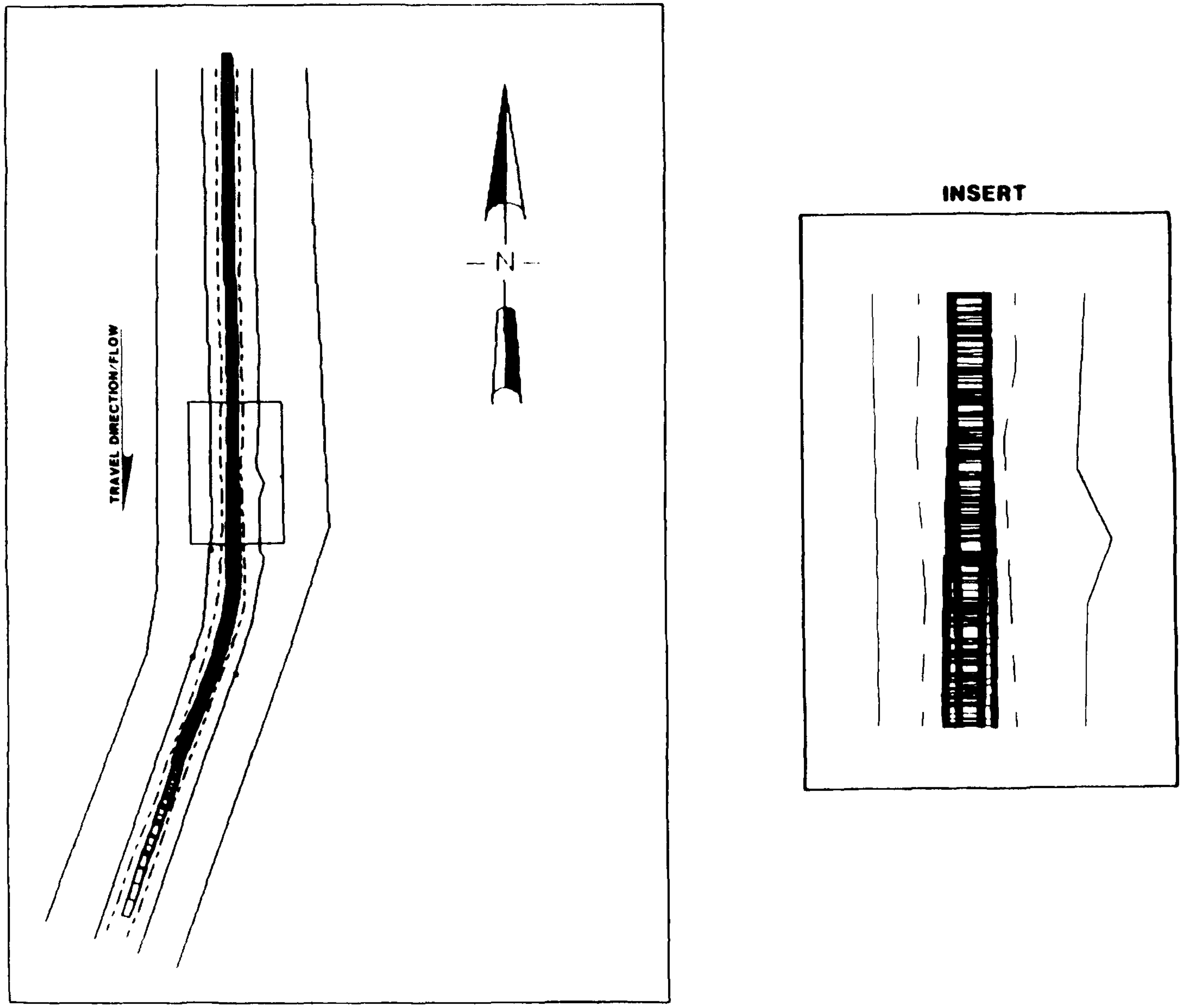


Figure 22. Ship track plots for Plan 1 for area C, with current and no wind

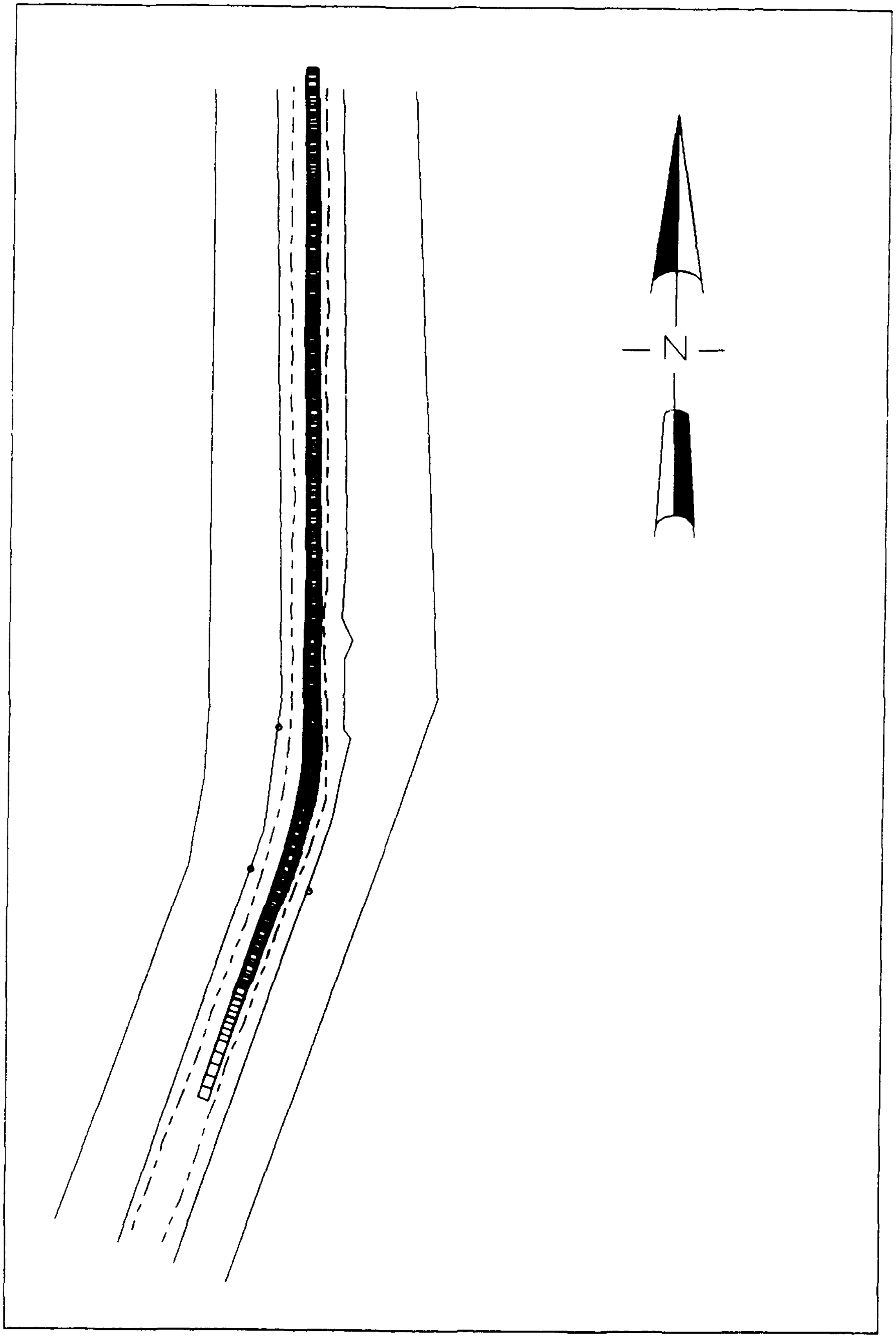


Figure 23. Ship track plots for Plan 2 for area C, no current and no wind, 610-ft ship

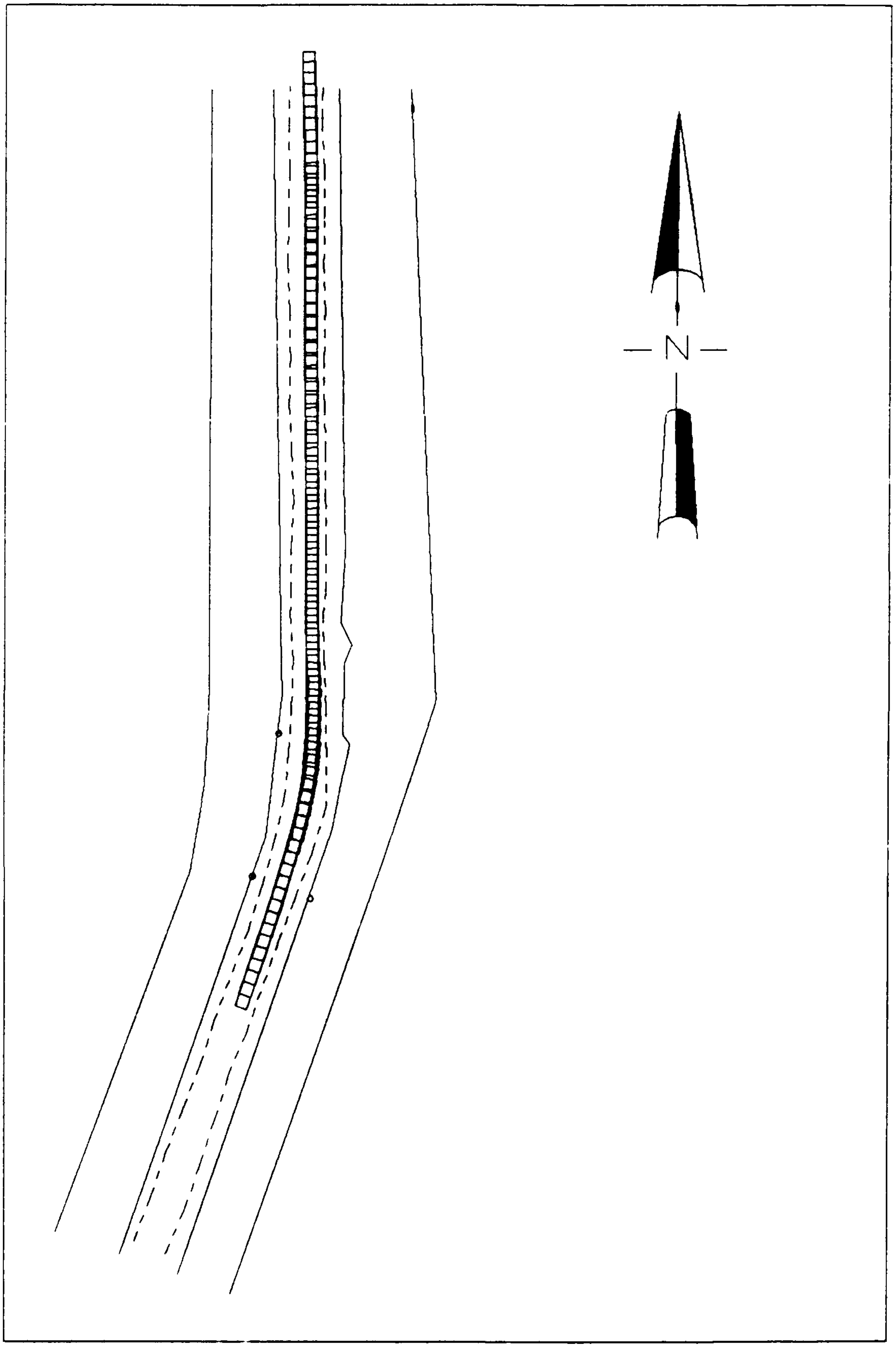


Figure 24. Ship track plots for Plan 2 for area C, no current and no wind, 855-ft ship

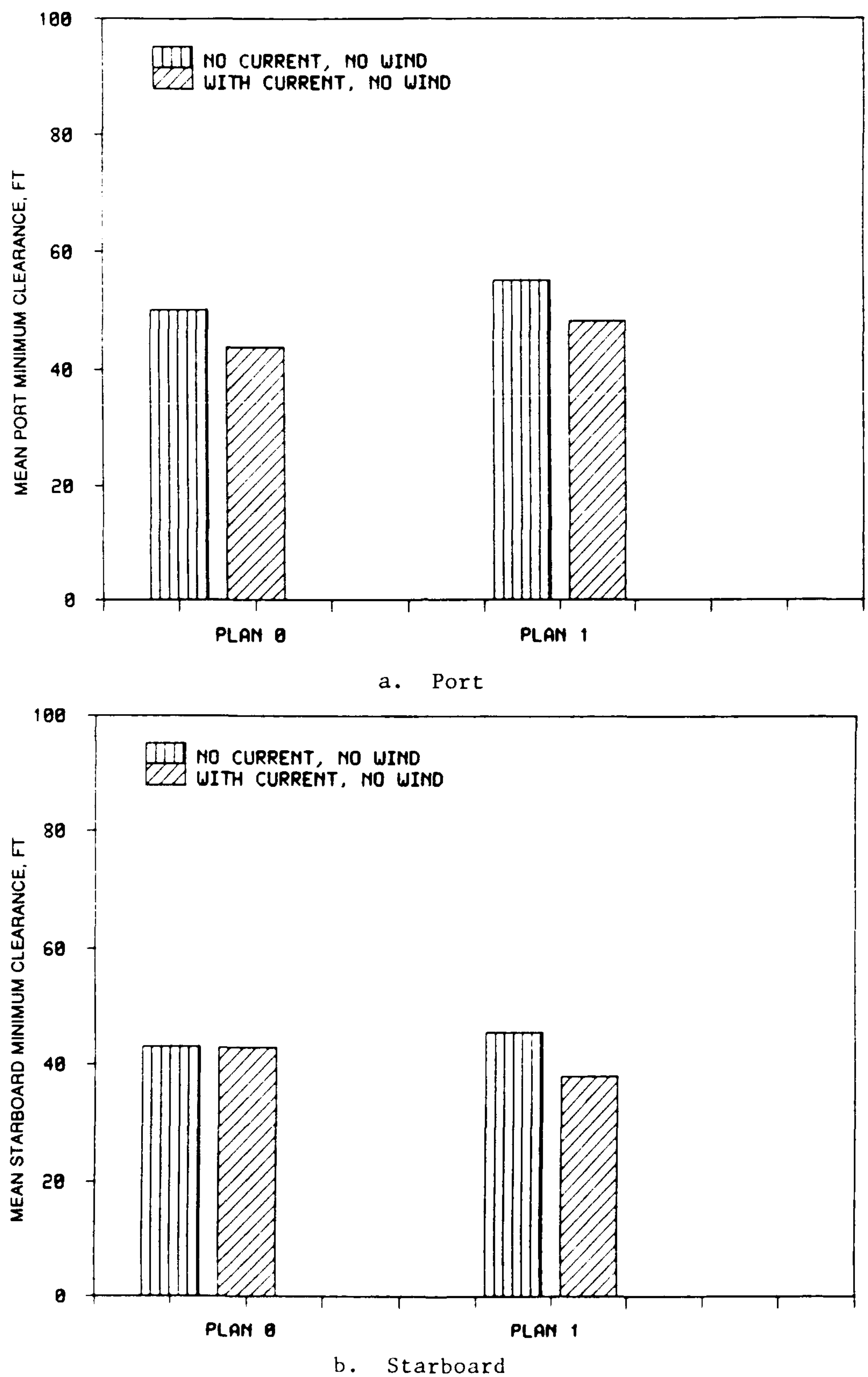
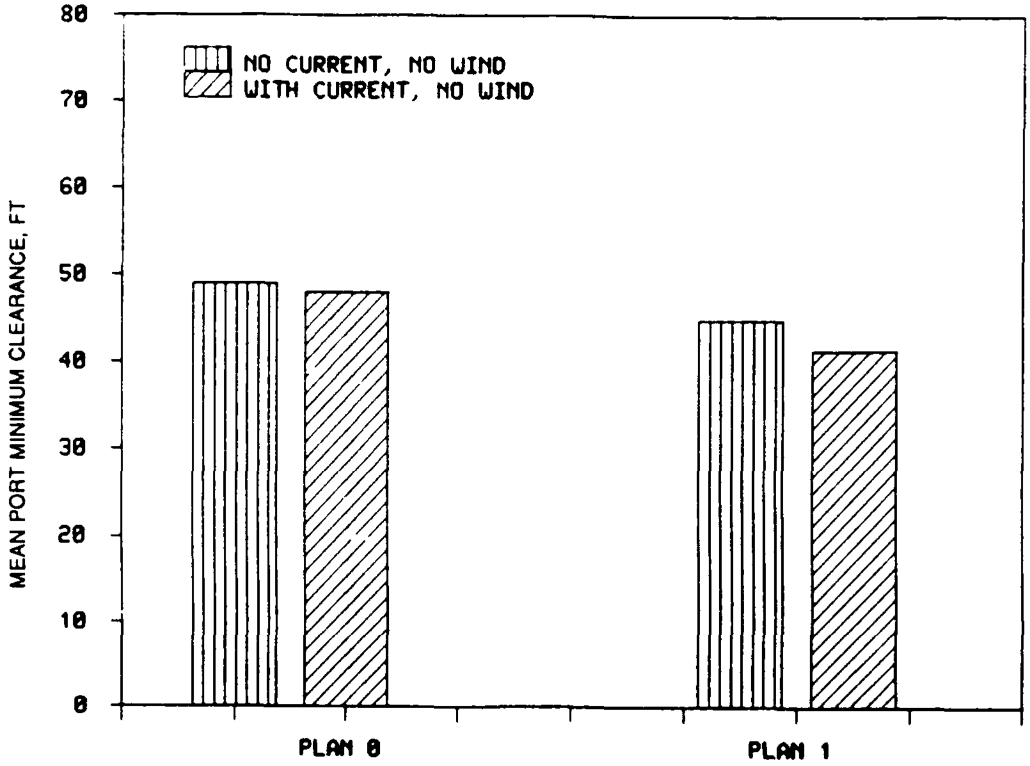
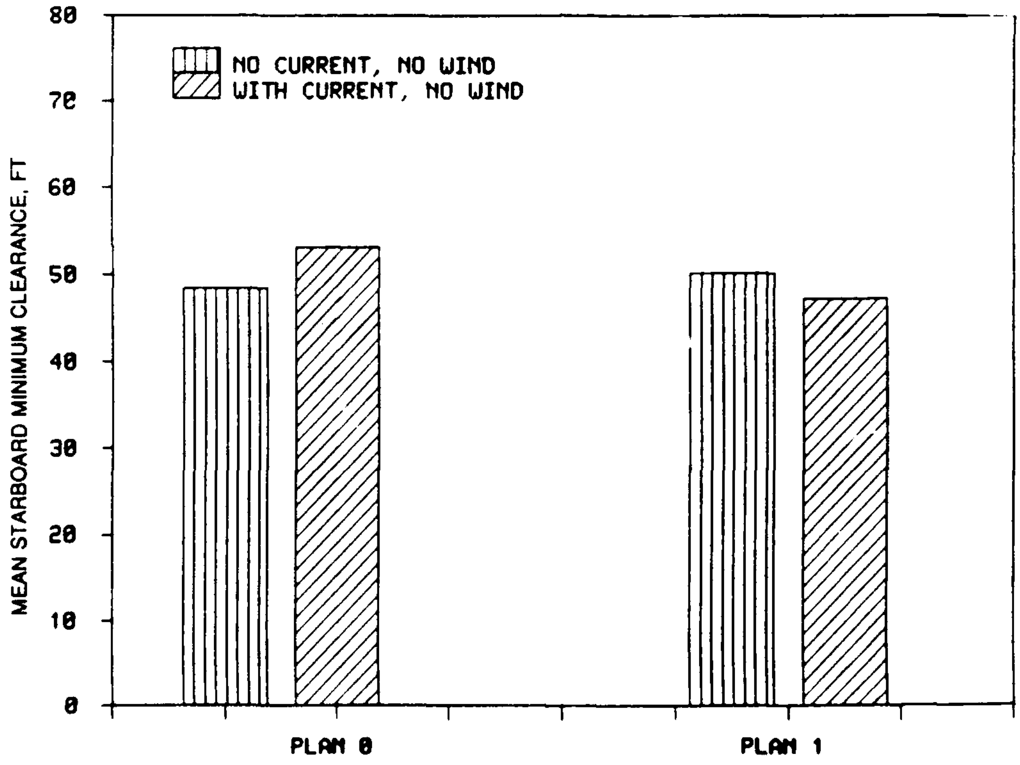


Figure 25. Port and starboard minimum clearance, area A, Plans 0 and 1, with and without current

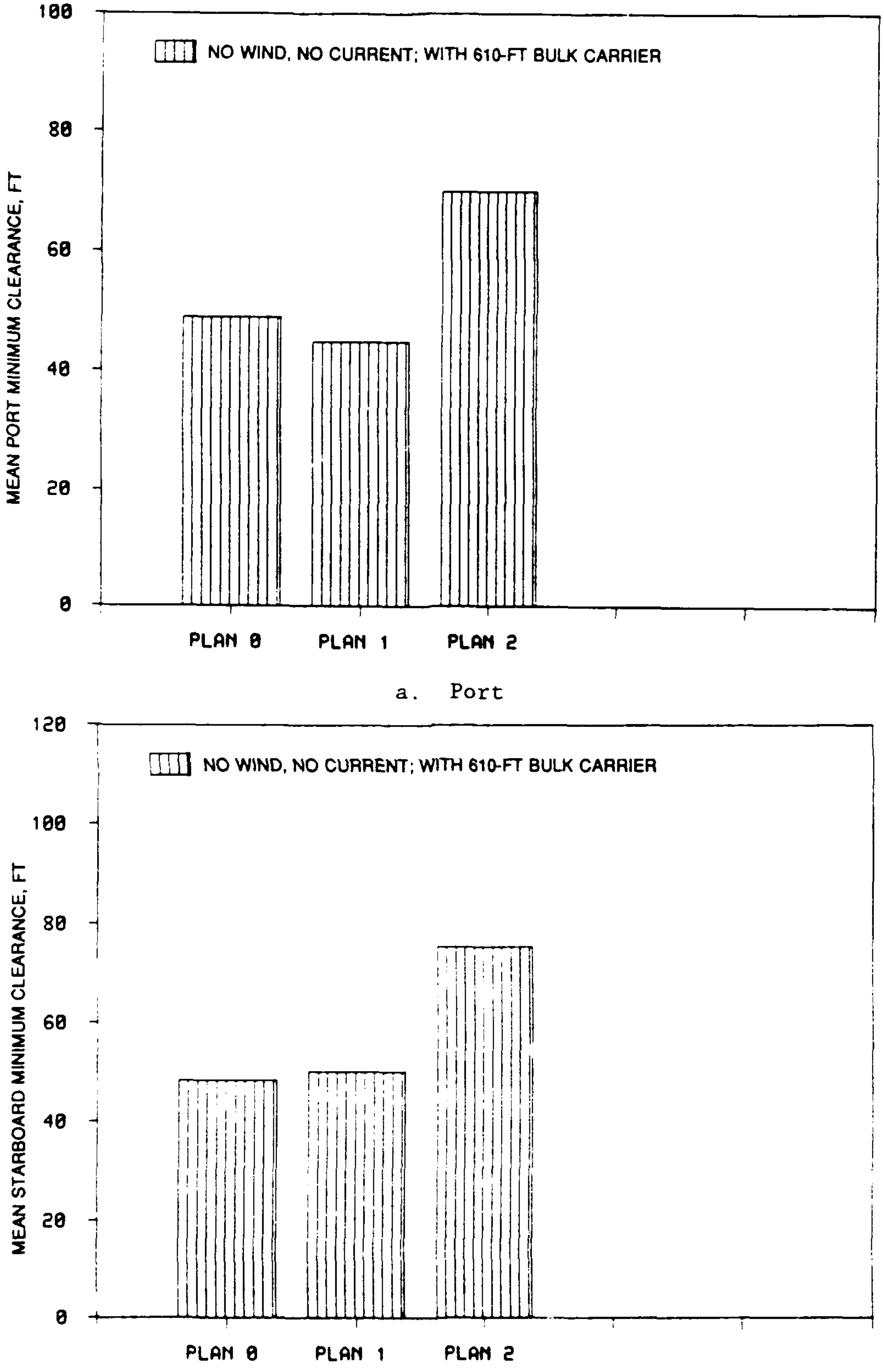


a. Port



b. Starboard

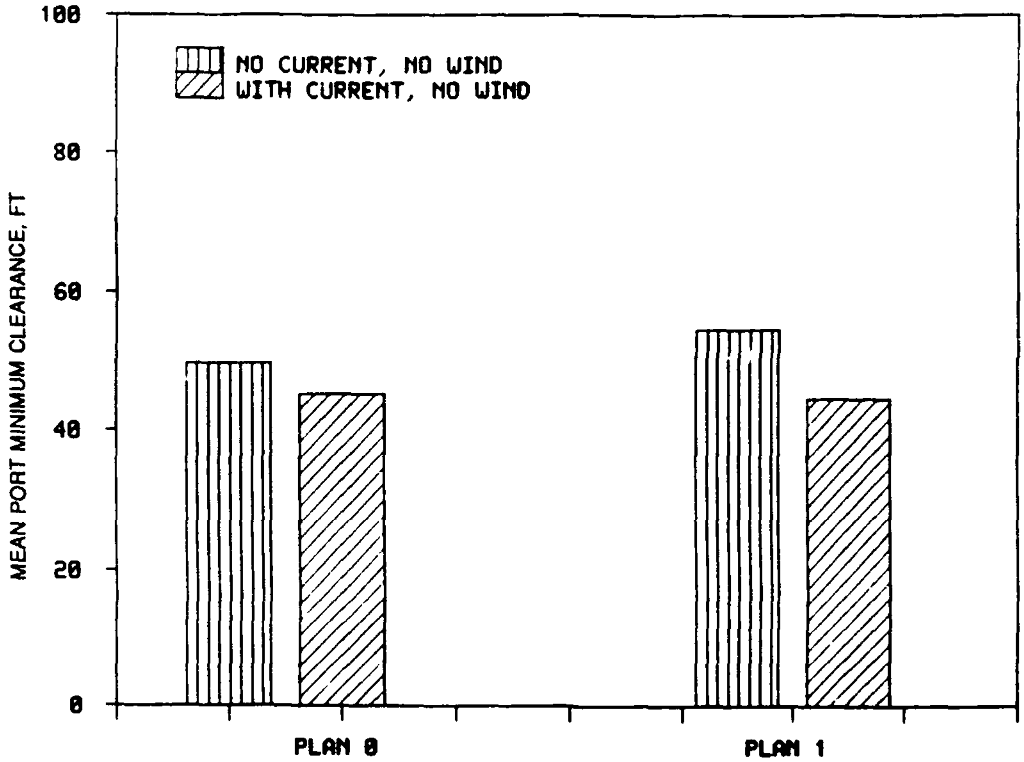
Figure 26. Mean and starboard minimum clearance, area B, Plans 0 and 1, with and without current



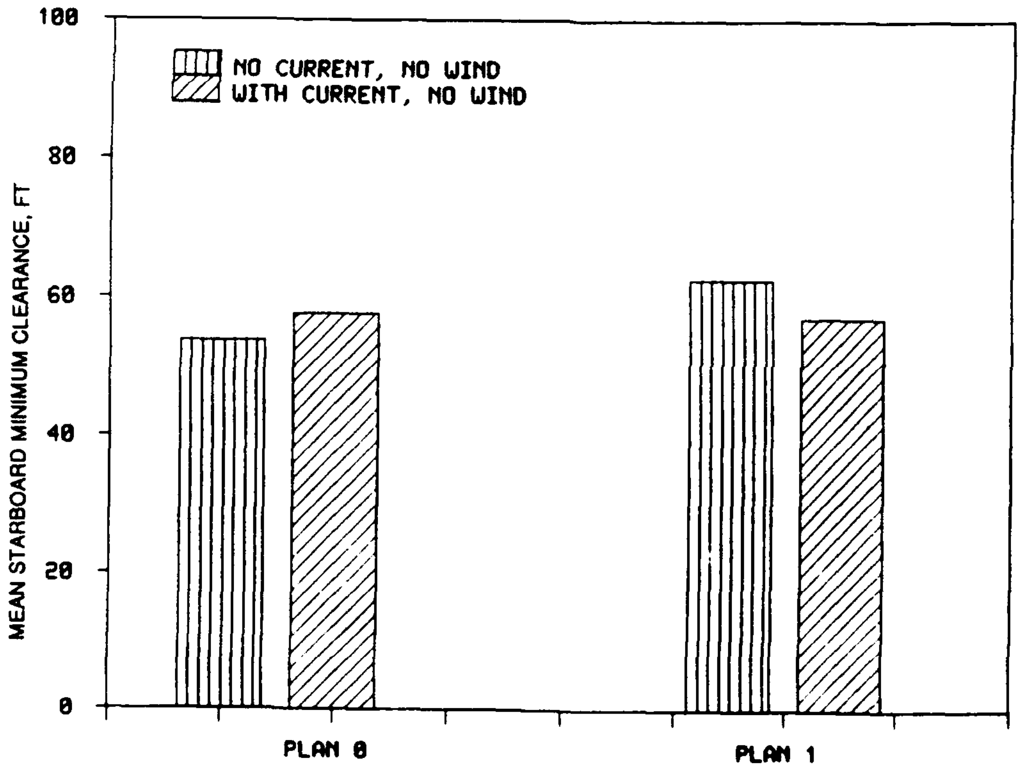
a. Port

b. Starboard

Figure 27. Mean port and starboard minimum clearance, area B, comparison of Plans 0, 1, and 2; no current, no wind



a. Port



b. Starboard

Figure 28. Mean port and starboard minimum clearance, area C, Plans 0 and 1, with and without current

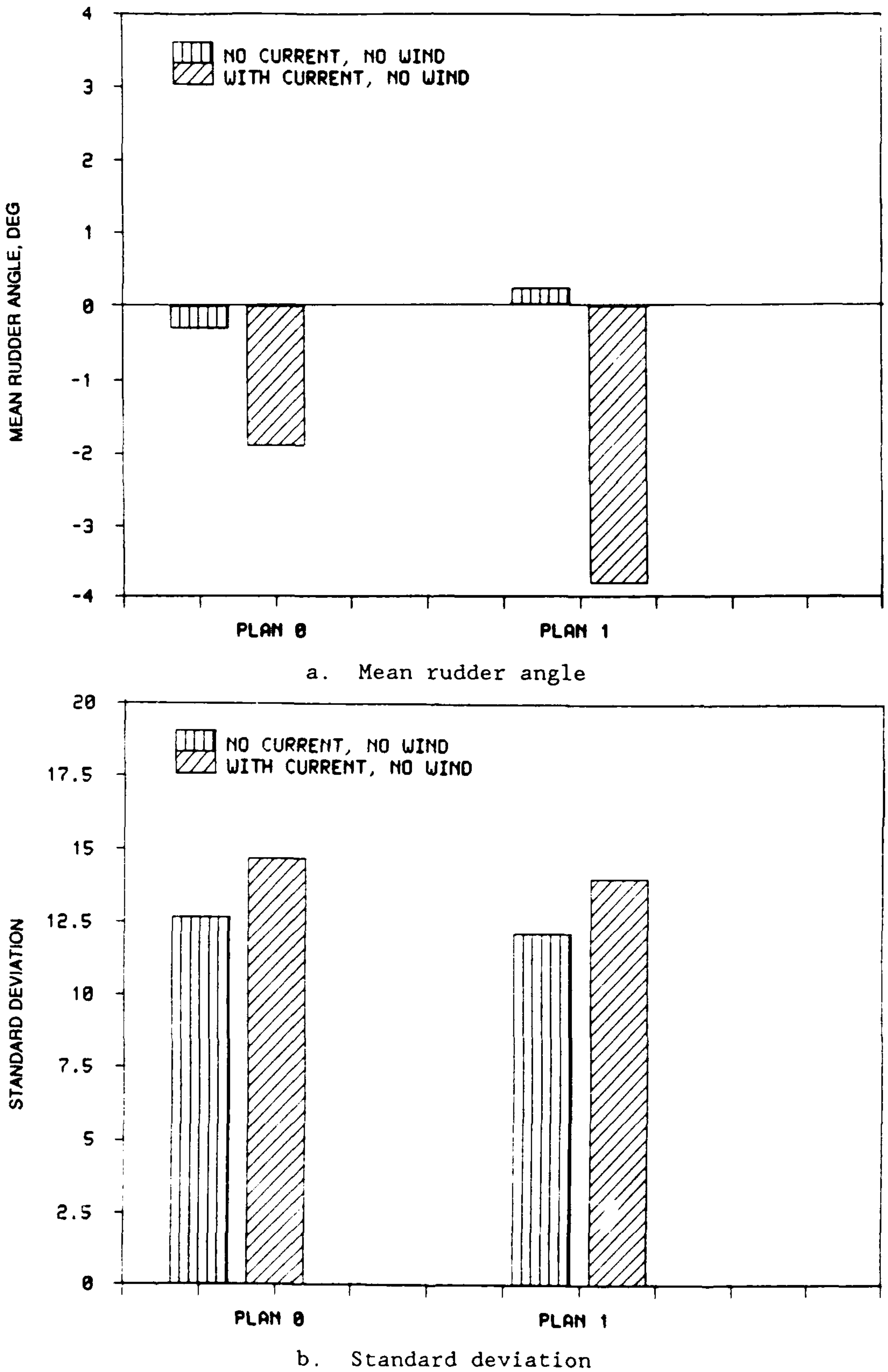
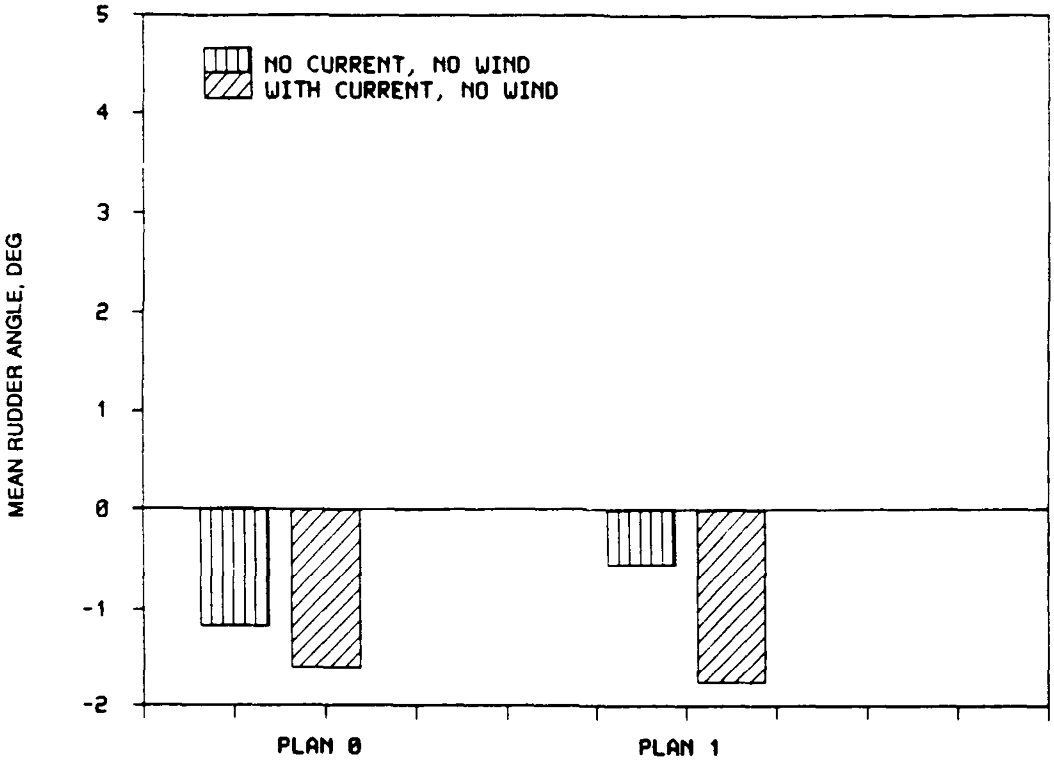
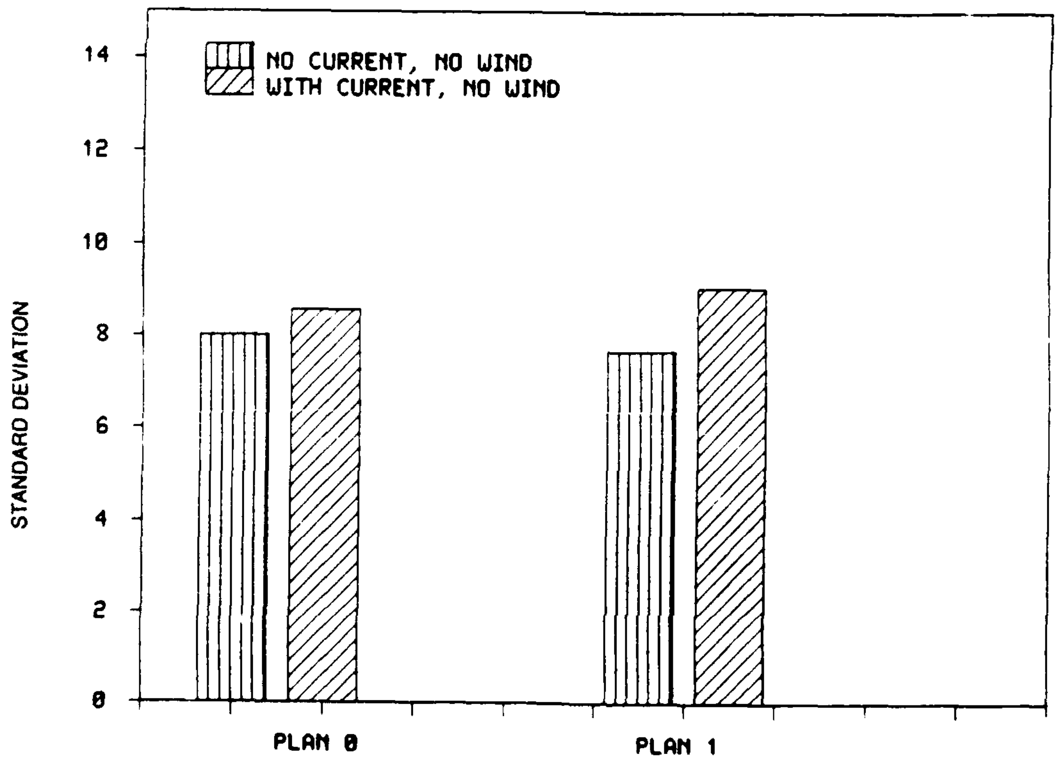


Figure 29. Mean rudder angle and standard deviation, area A, Plans 0 and 1, with and without current

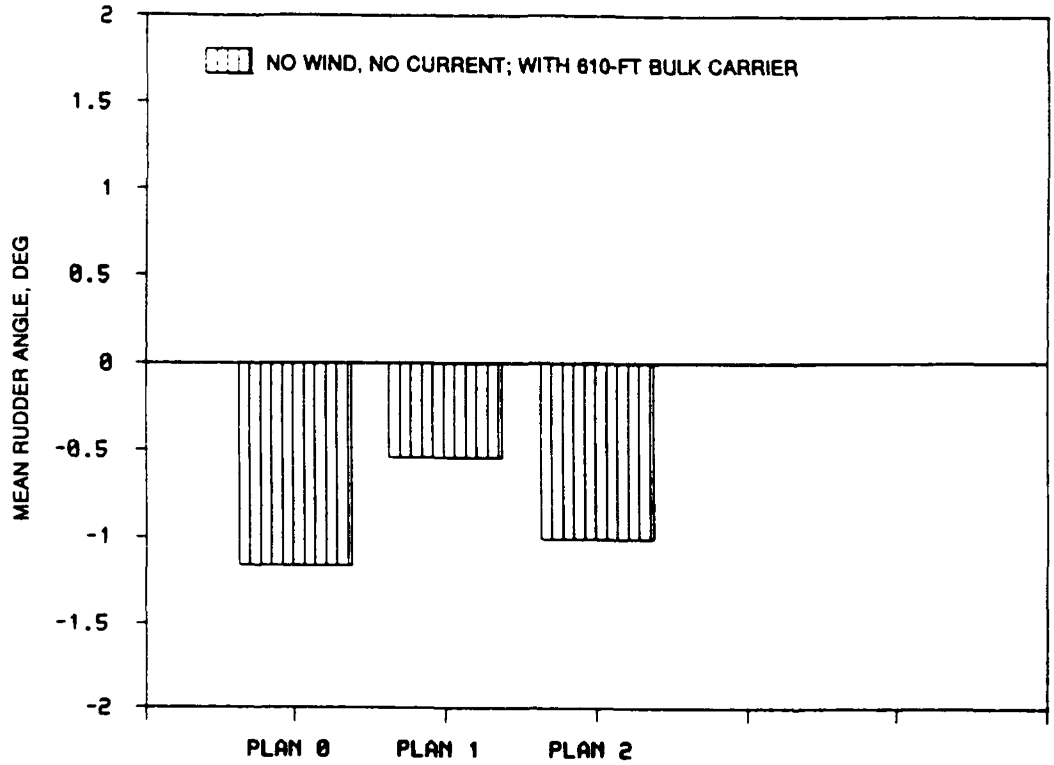


a. Mean rudder angle

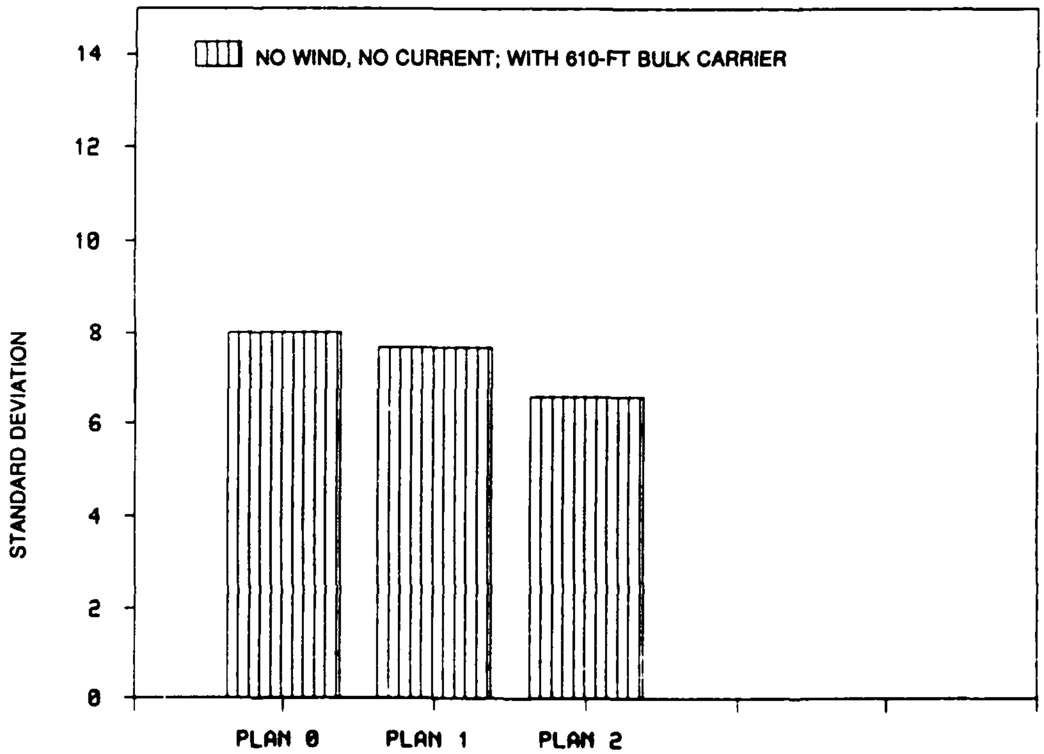


b. Standard deviation

Figure 30. Mean rudder angle and standard deviation, area B, Plans 0 and 1, with and without current

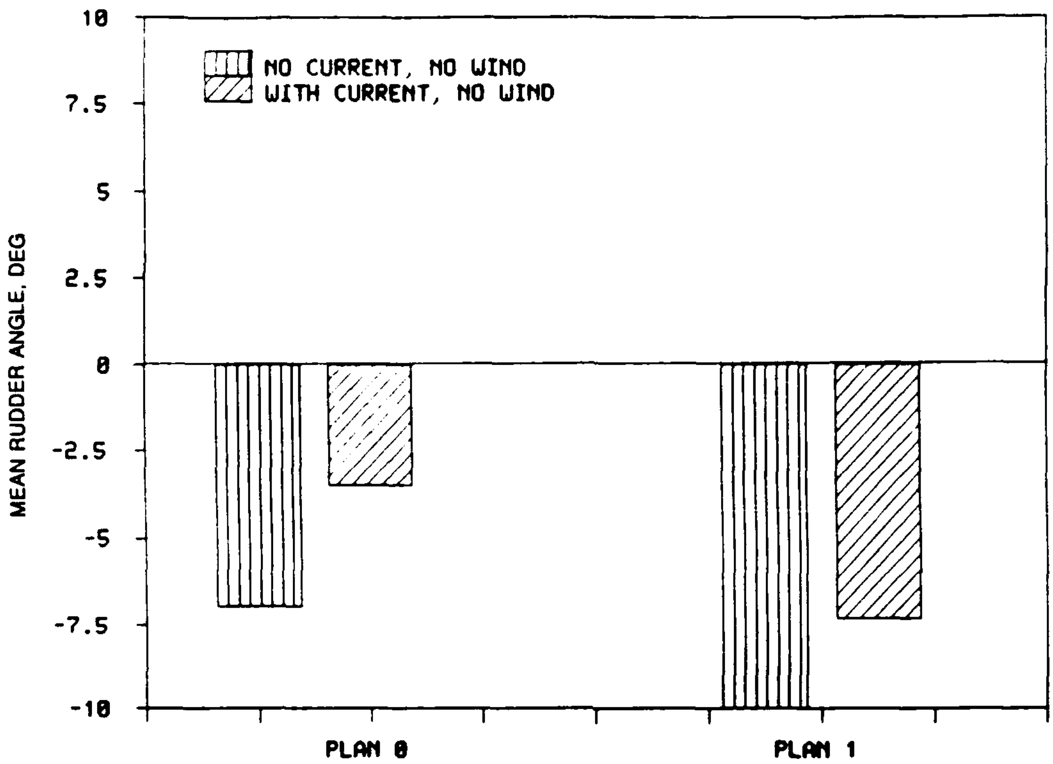


a. Mean rudder angle

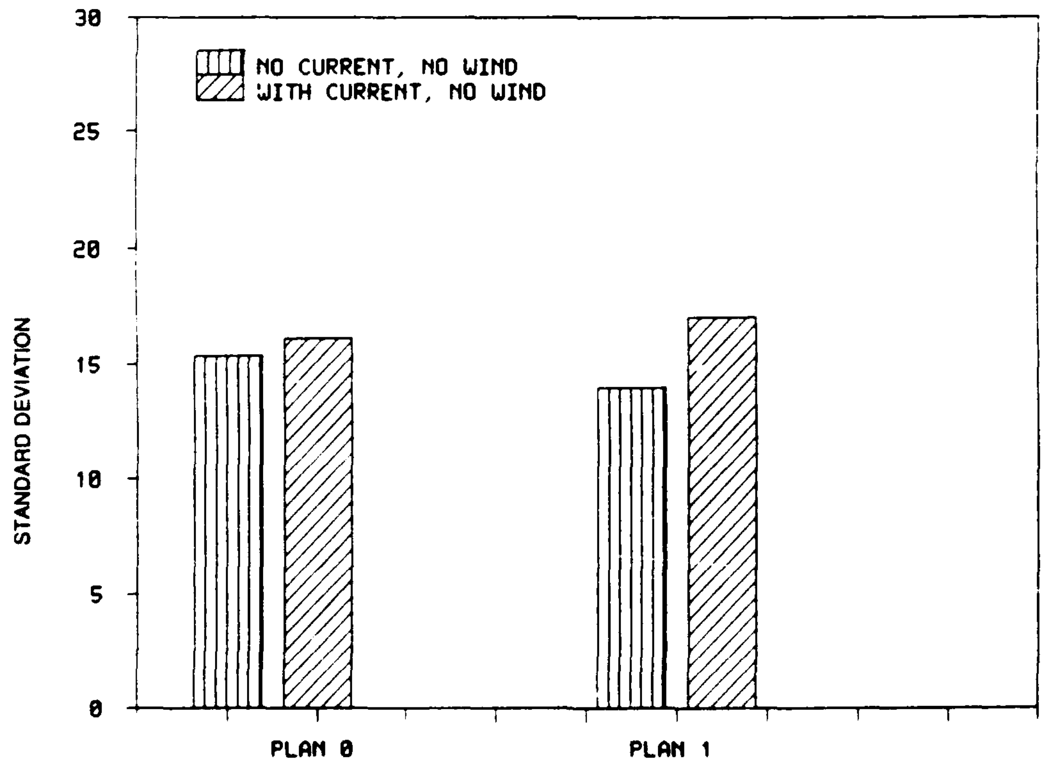


b. Standard deviation

Figure 31. Mean rudder angle and standard deviation, area B, Plans 0, 1, and 2, no current and no wind

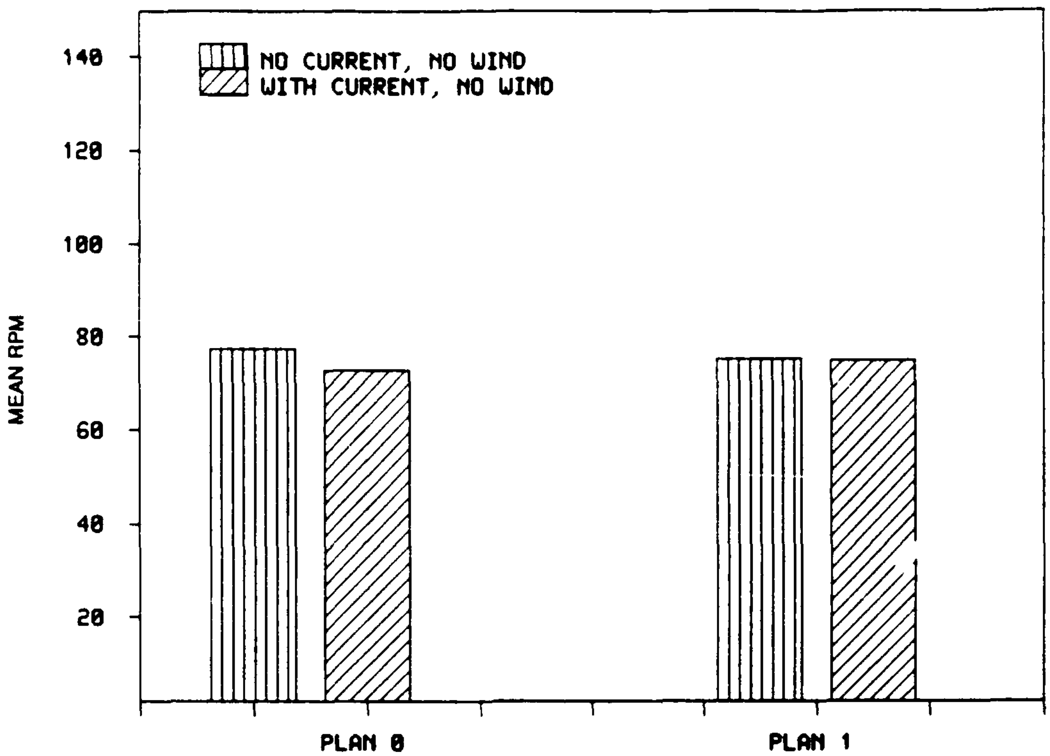


a. Mean rudder angle

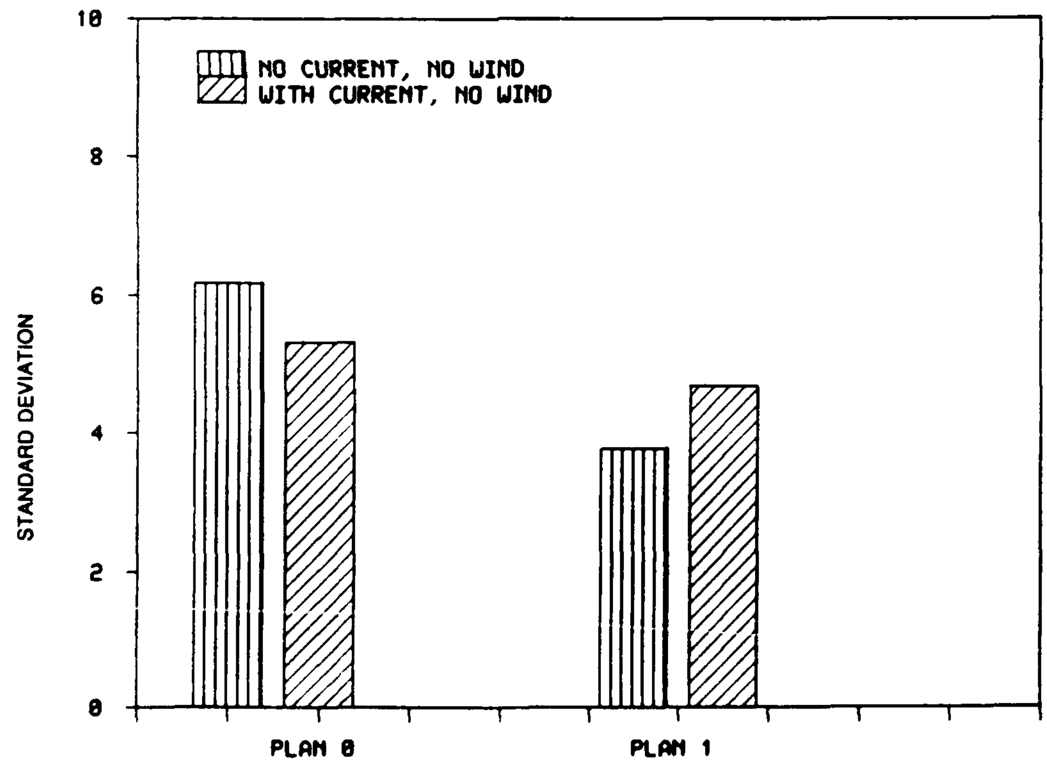


b. Standard deviation

Figure 32. Mean rudder angle and standard deviation, area C, Plans 0 and 1, with and without current

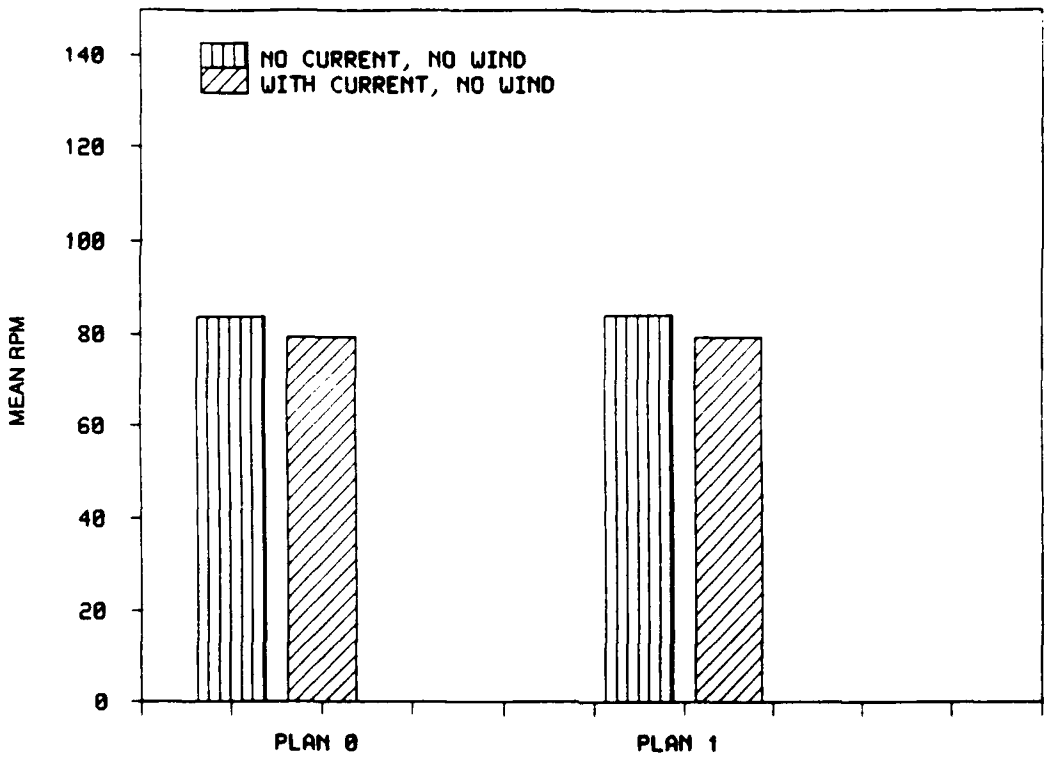


a. Mean rpm

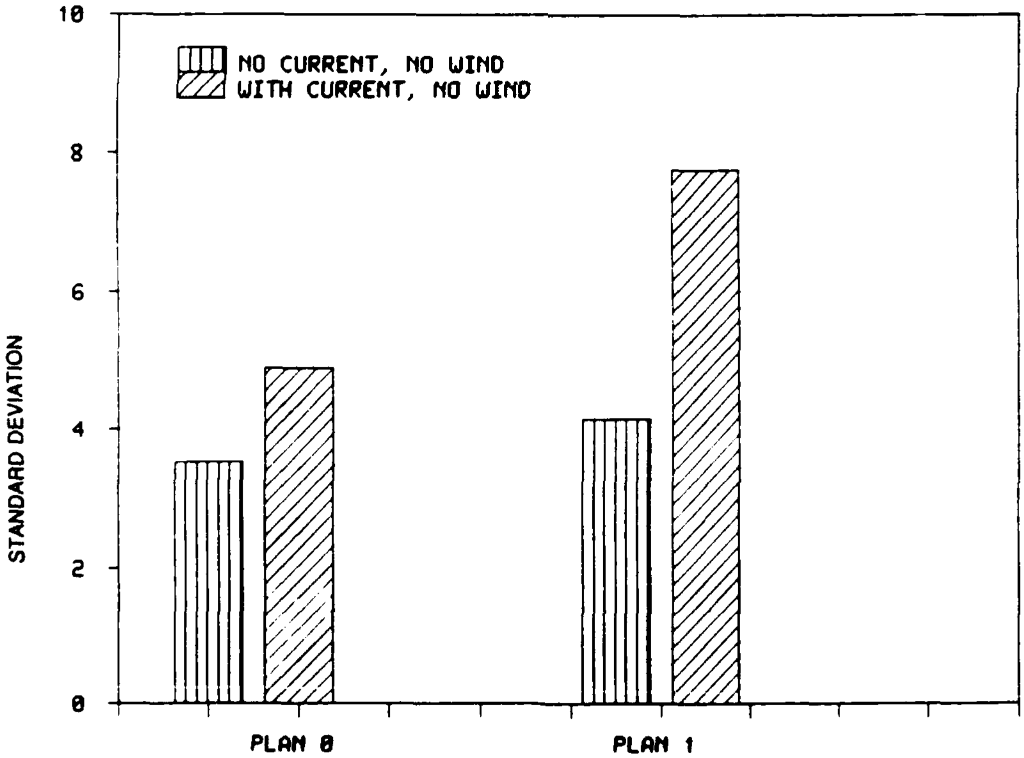


b. Standard deviation

Figure 33. Mean rpm and standard deviation, area A, Plans 0 and 1, with and without current

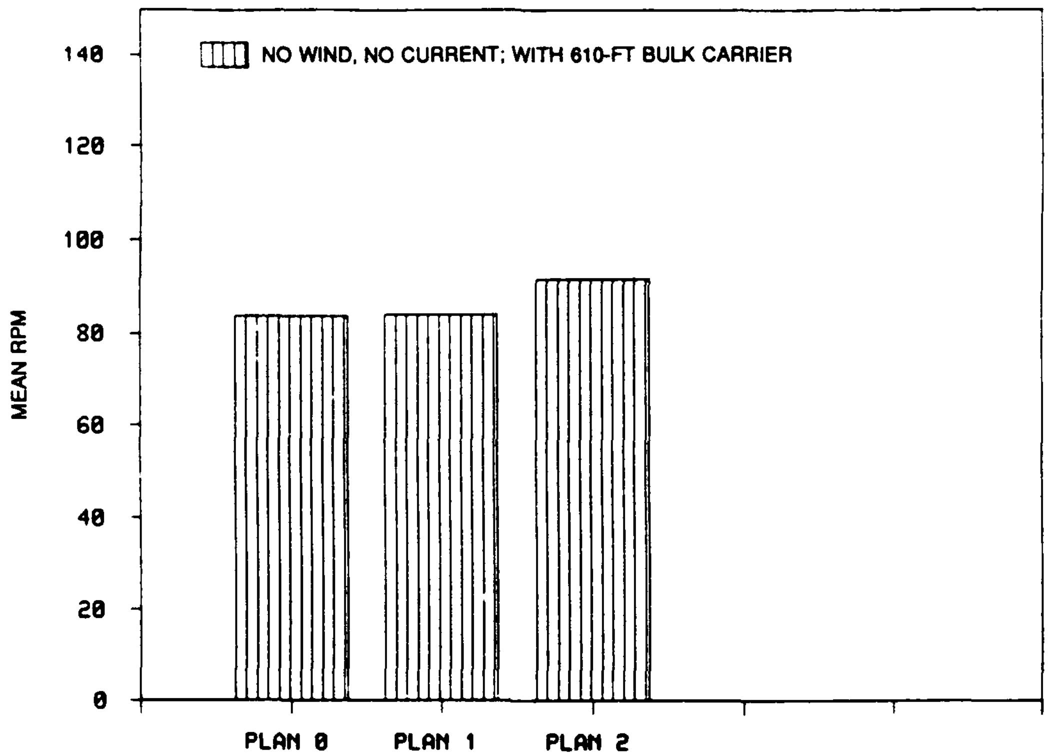


a. Mean rpm

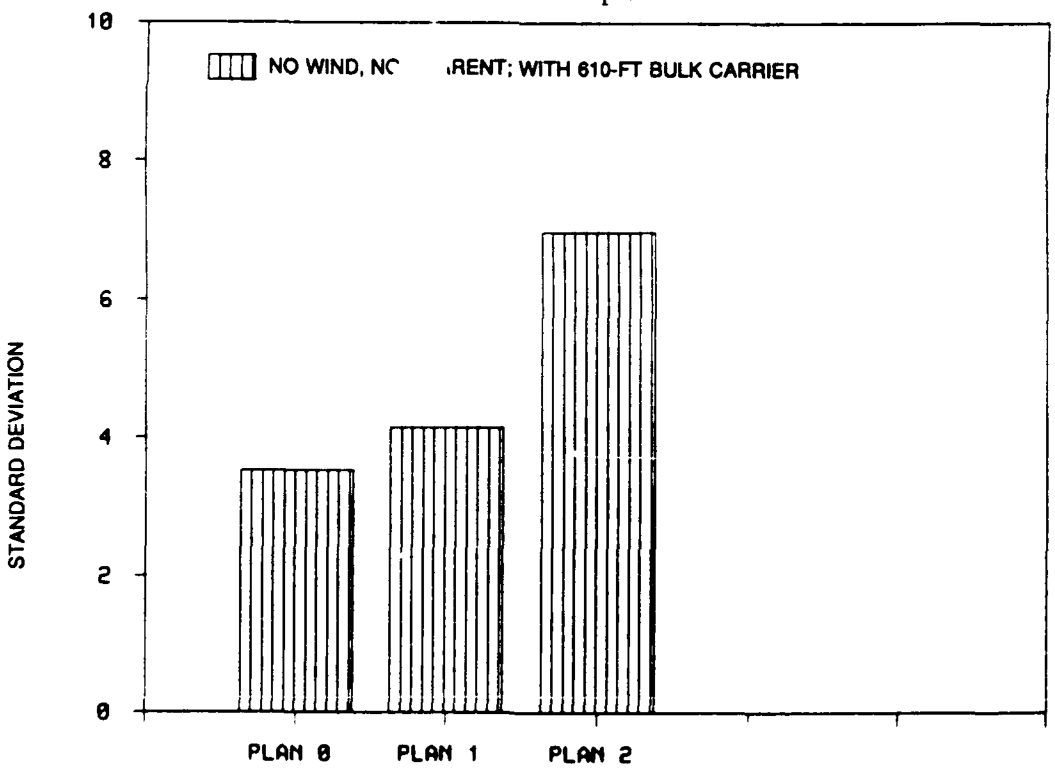


b. Standard deviation

Figure 34. Mean rpm and standard deviation, area B, Plans 0 and 1, with and without current

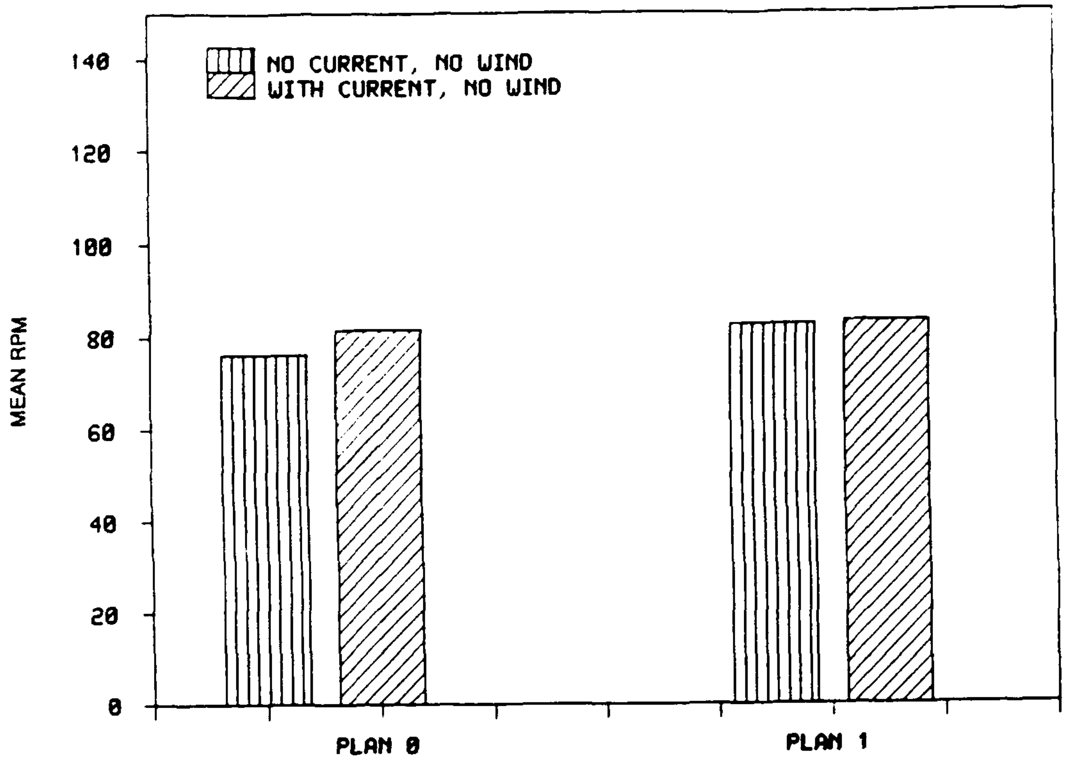


a. Mean rpm

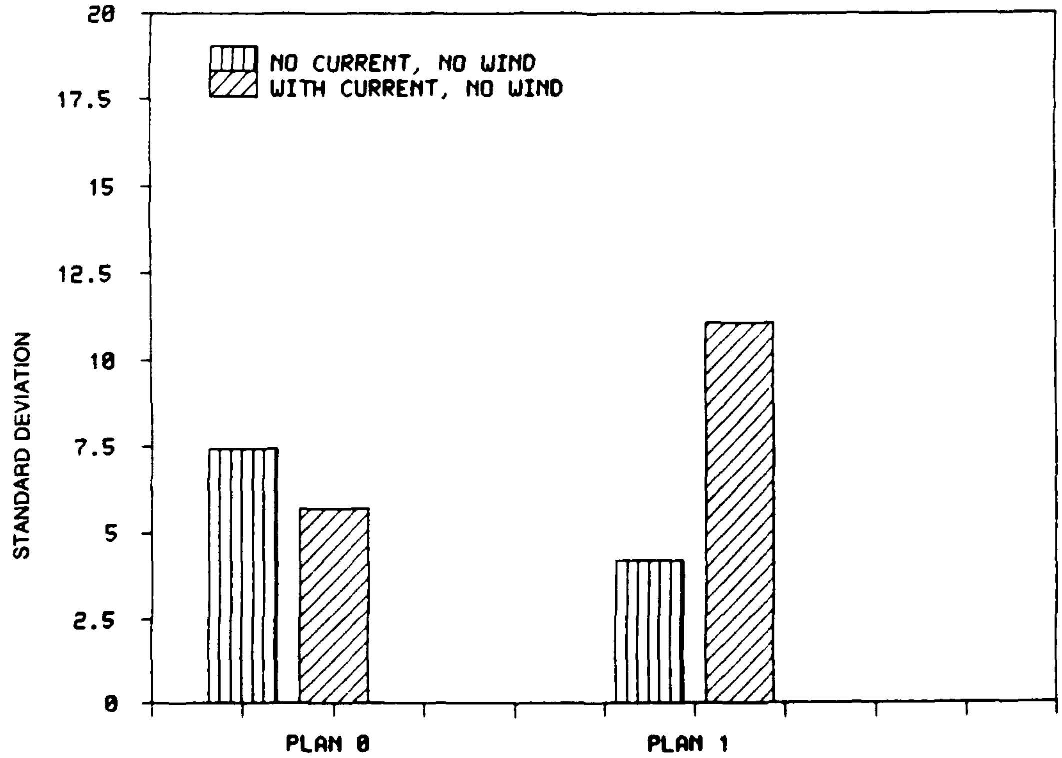


b. Standard deviation

Figure 35. Mean rpm and standard deviation, area B, Plans 0, 1, and 2, no current and no wind

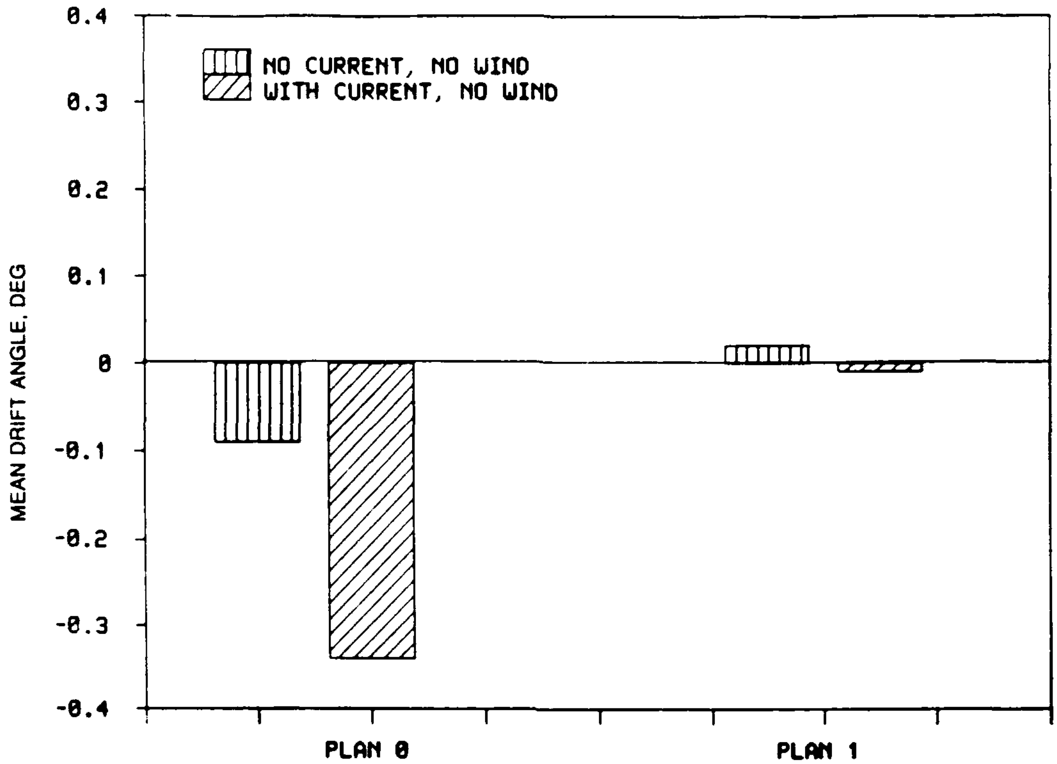


a. Mean rpm

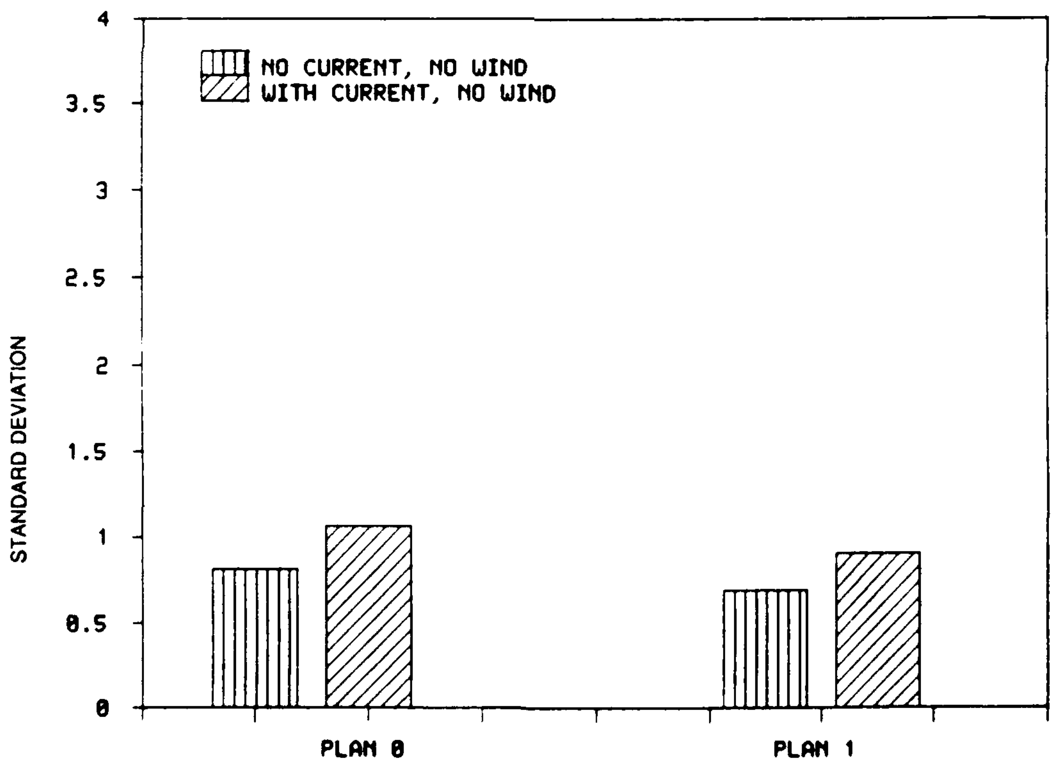


b. Standard deviation

Figure 36. Mean rpm and standard deviation, area C, Plans 0 and 1, with and without current

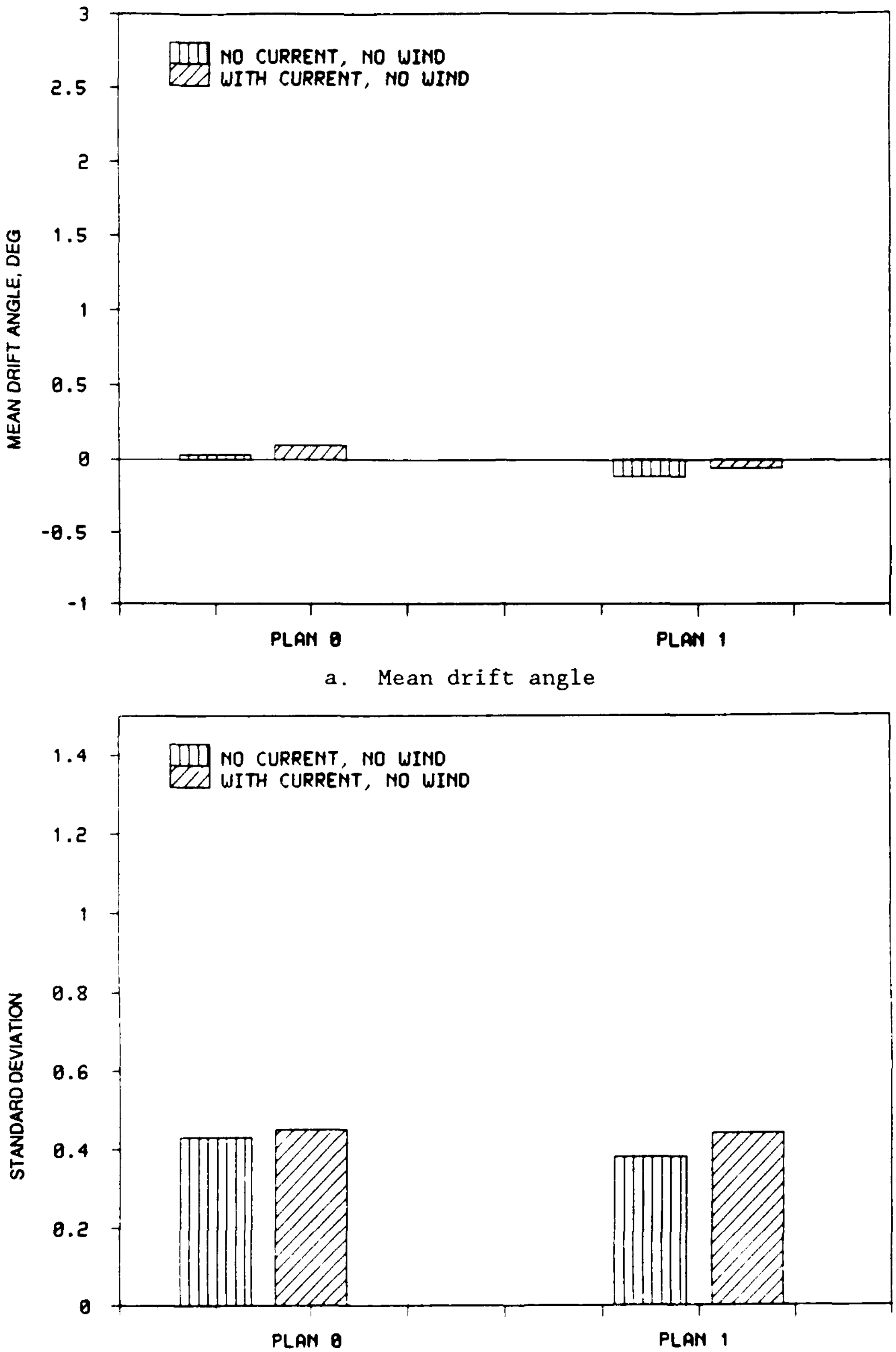


a. Mean drift angle



b. Standard deviation

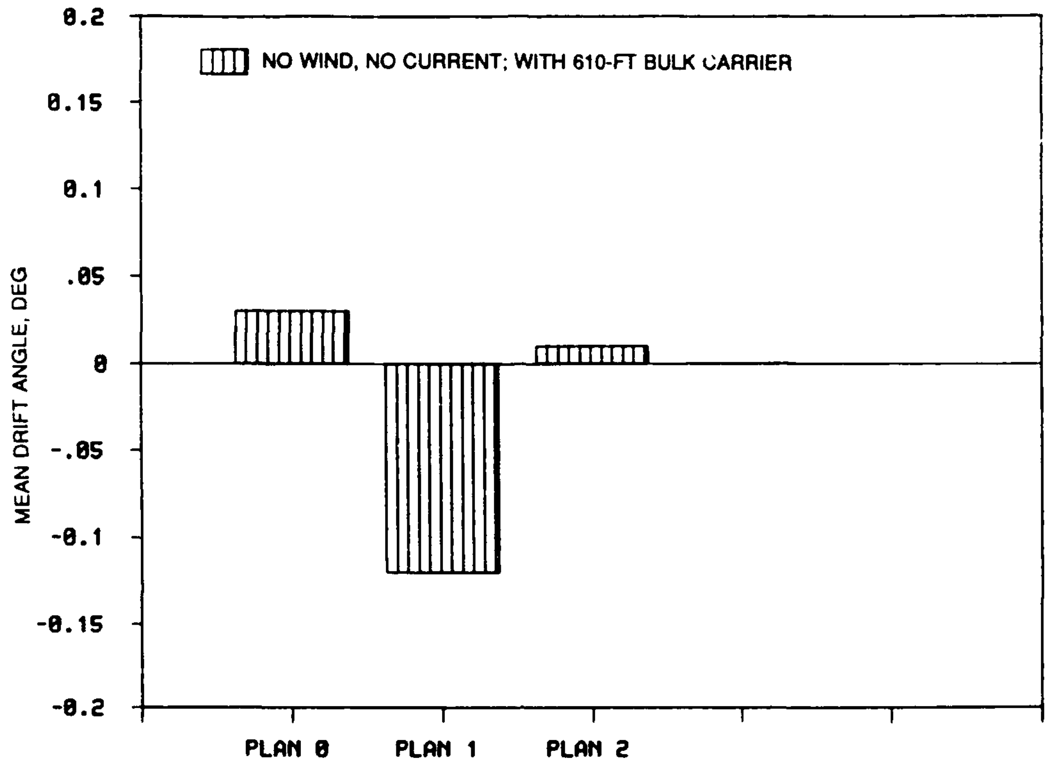
Figure 37. Mean drift angle and standard deviation, area A, Plans 0 and 1, with and without current



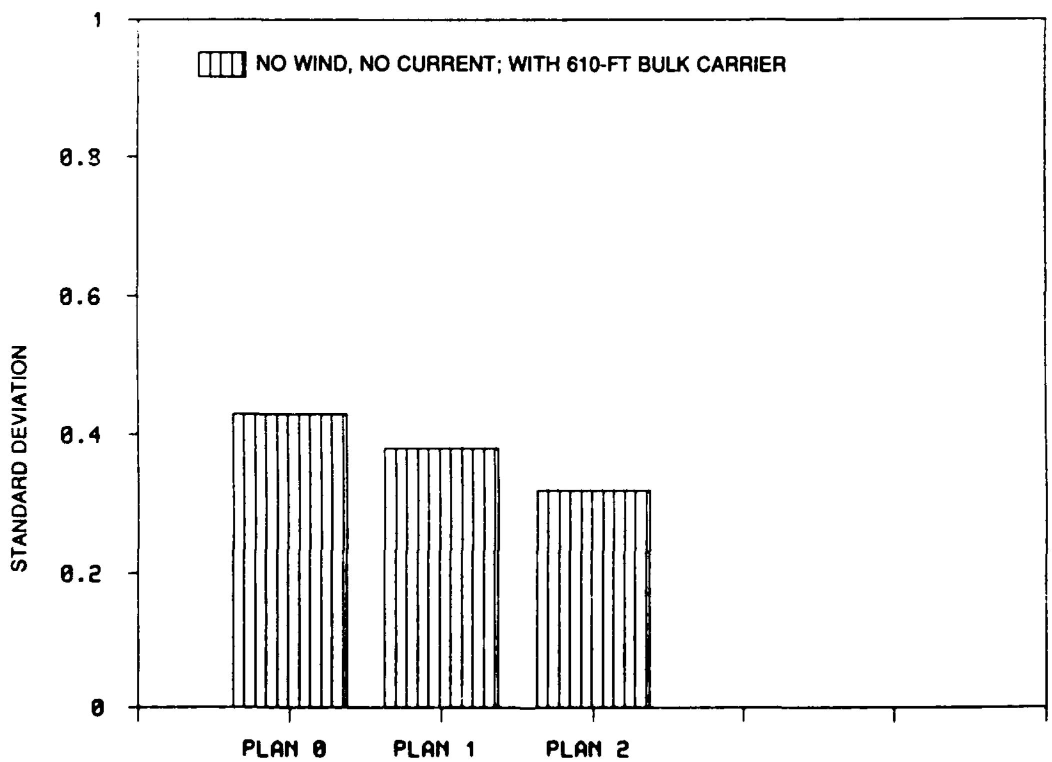
a. Mean drift angle

b. Standard deviation

Figure 38. Mean drift angle and standard deviation, area B, Plans 0 and 1, with and without current

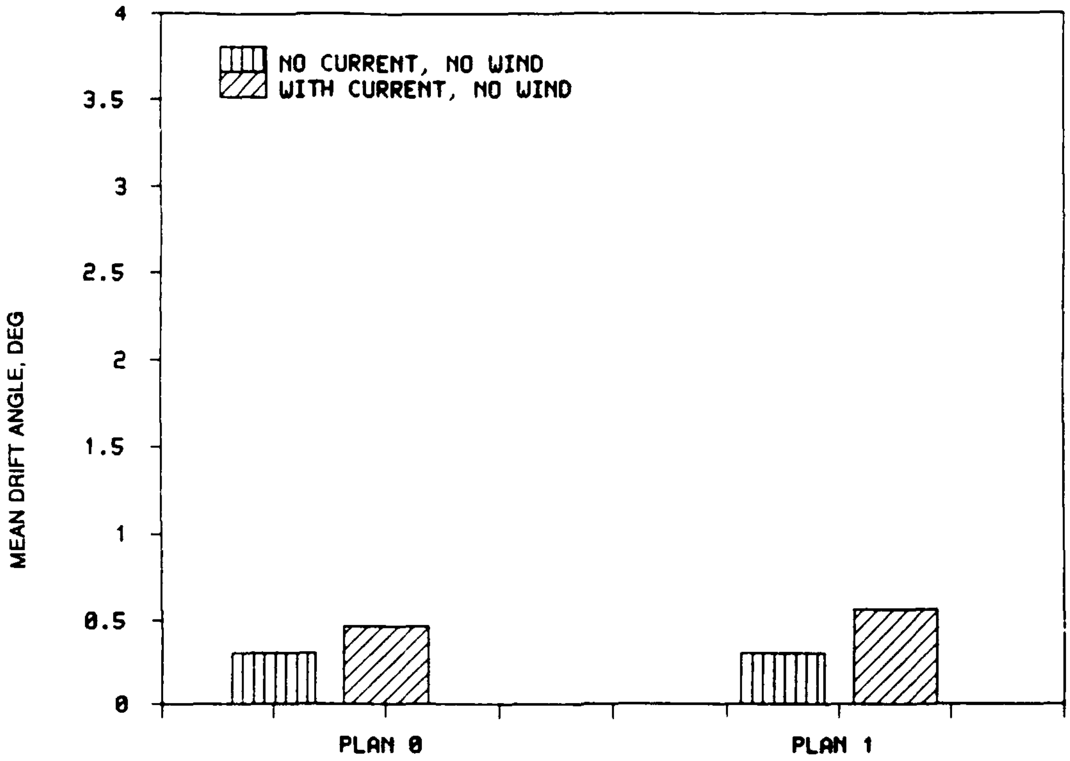


a. Mean drift angle

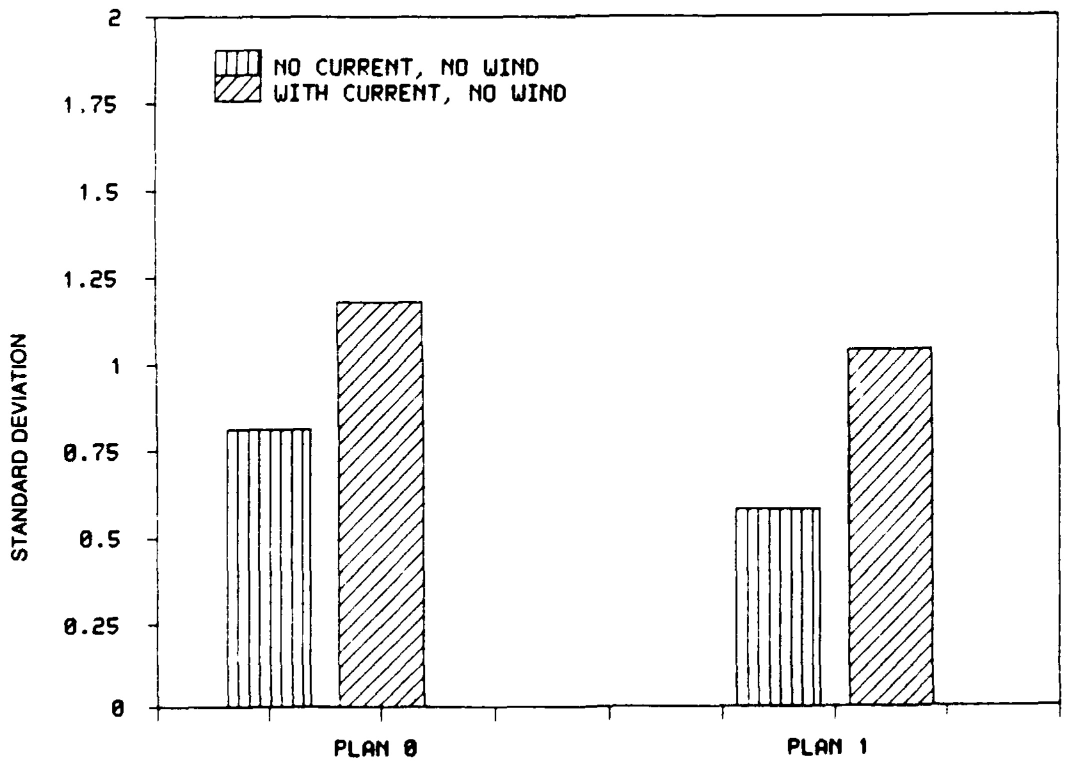


b. Standard deviation

Figure 39. Mean drift angle and standard deviation, area B, Plans 0, 1, and 2, no current and no wind

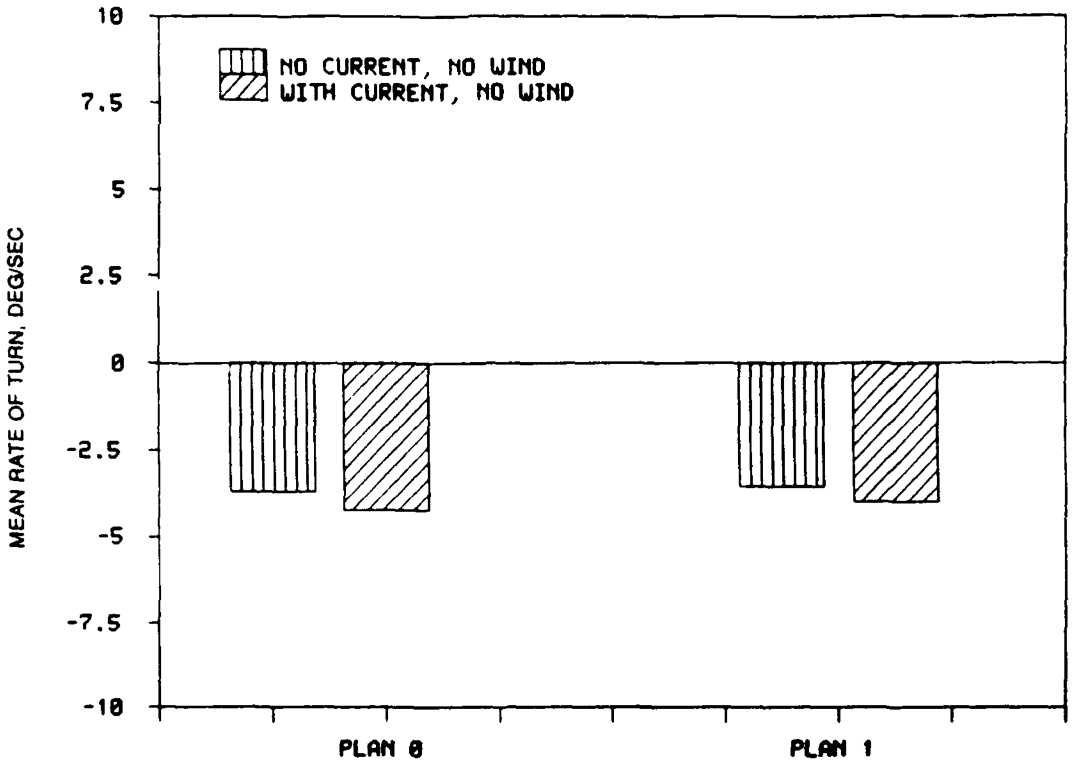


a. Mean drift angle

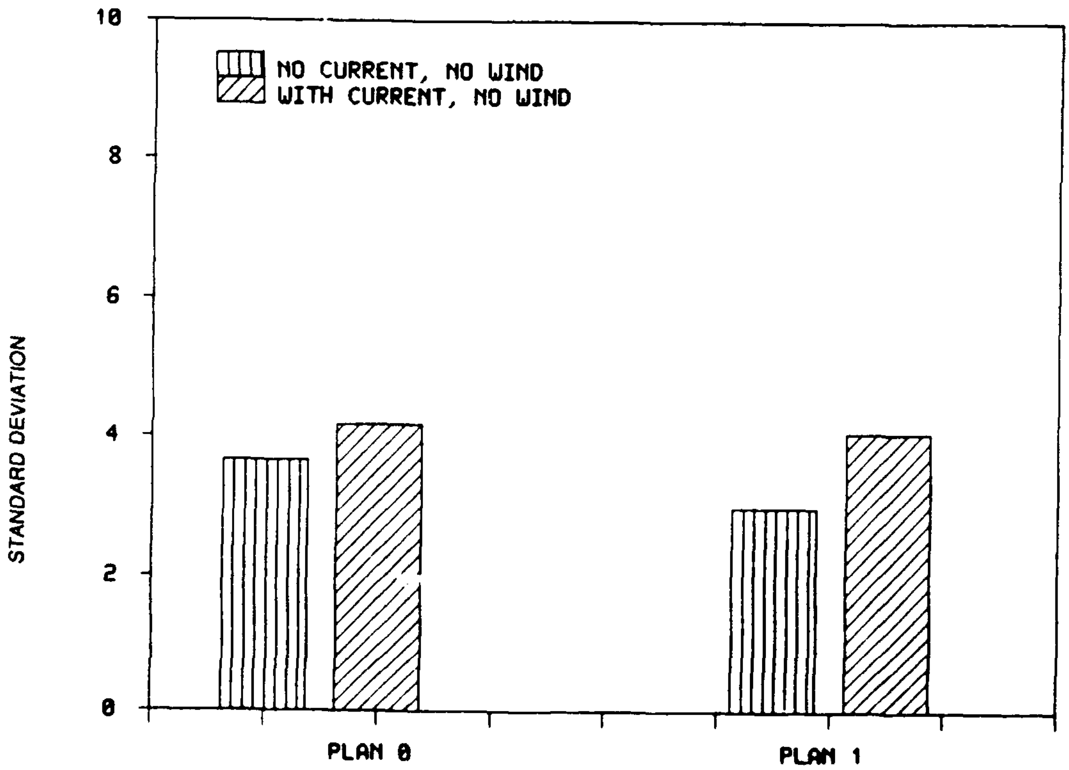


b. Standard deviation

Figure 40. Mean drift angle and standard deviation, area C, Plans 0 and 1, with and without current

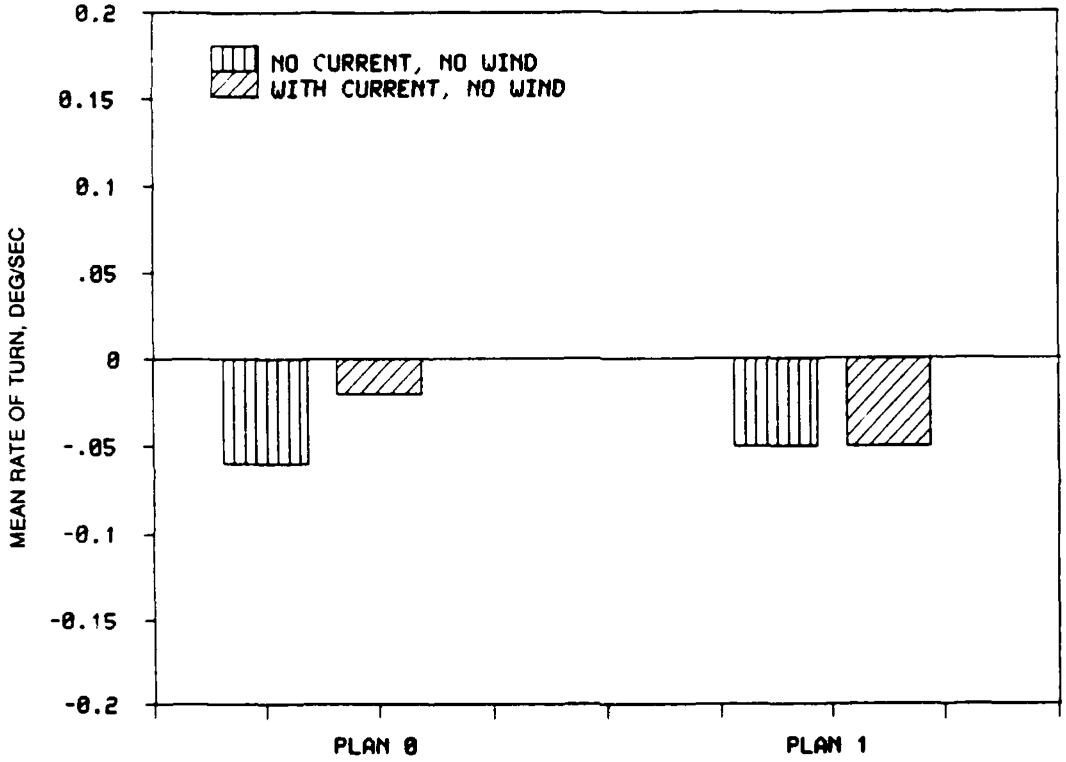


a. Mean rate of turn

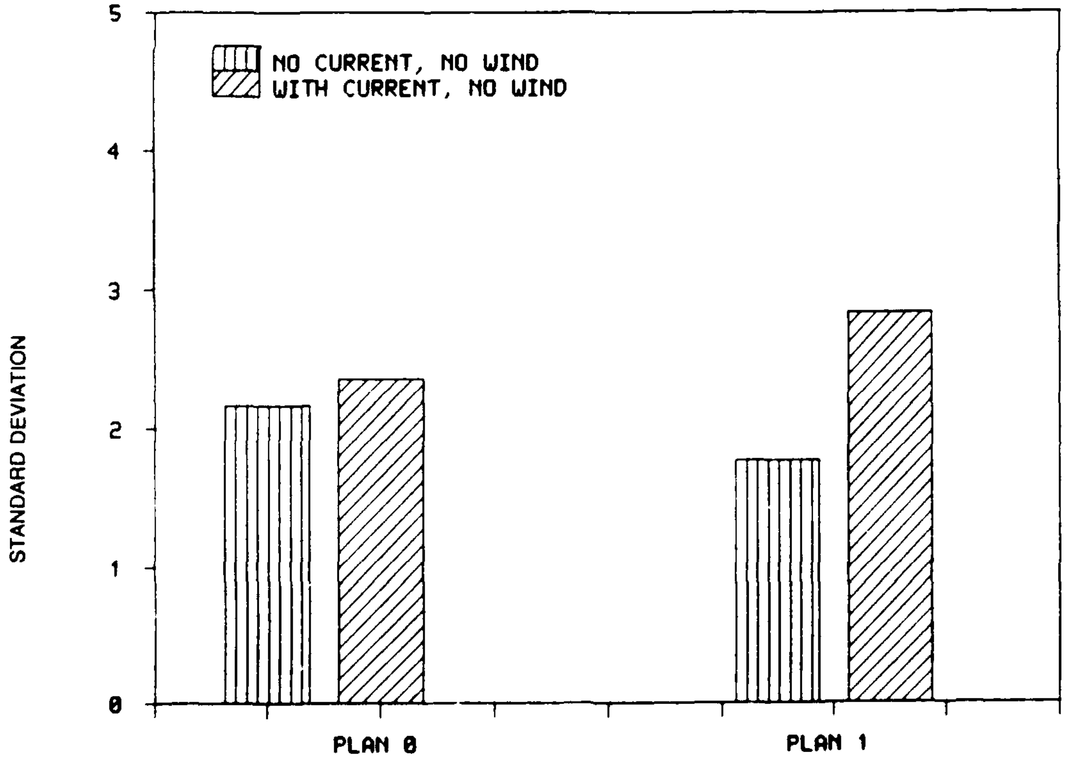


b. Standard deviation

Figure 41. Mean rate of turn and standard deviation, area A, Plans 0 and 1, with and without current

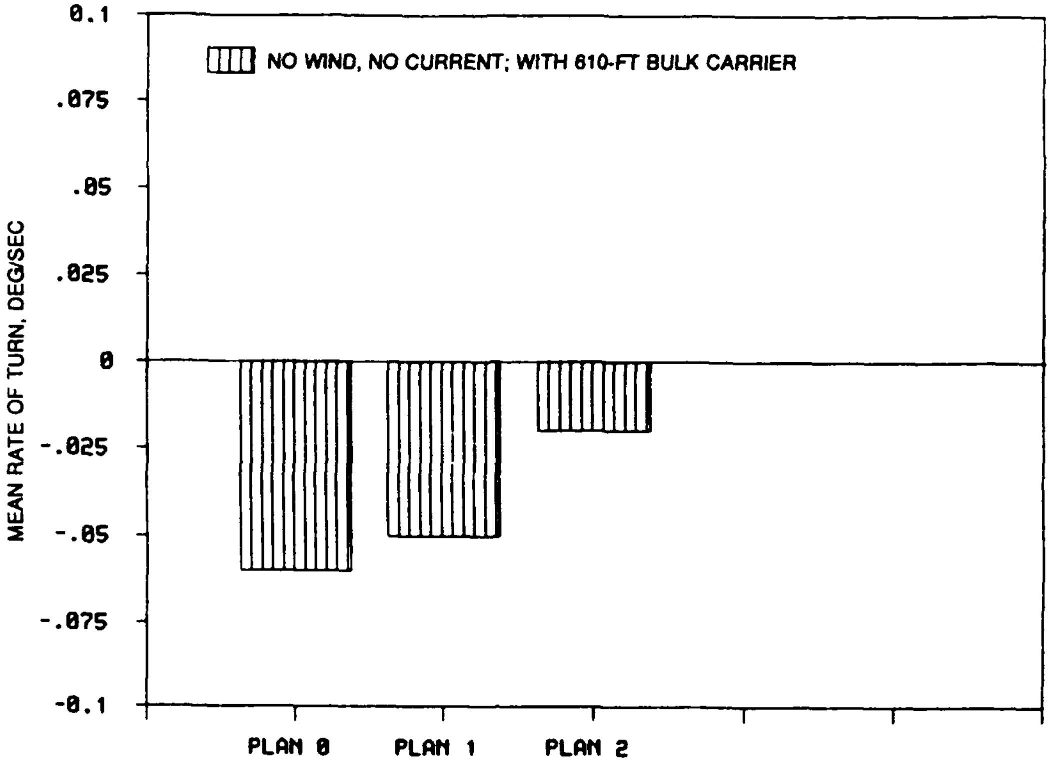


a. Mean rate of turn

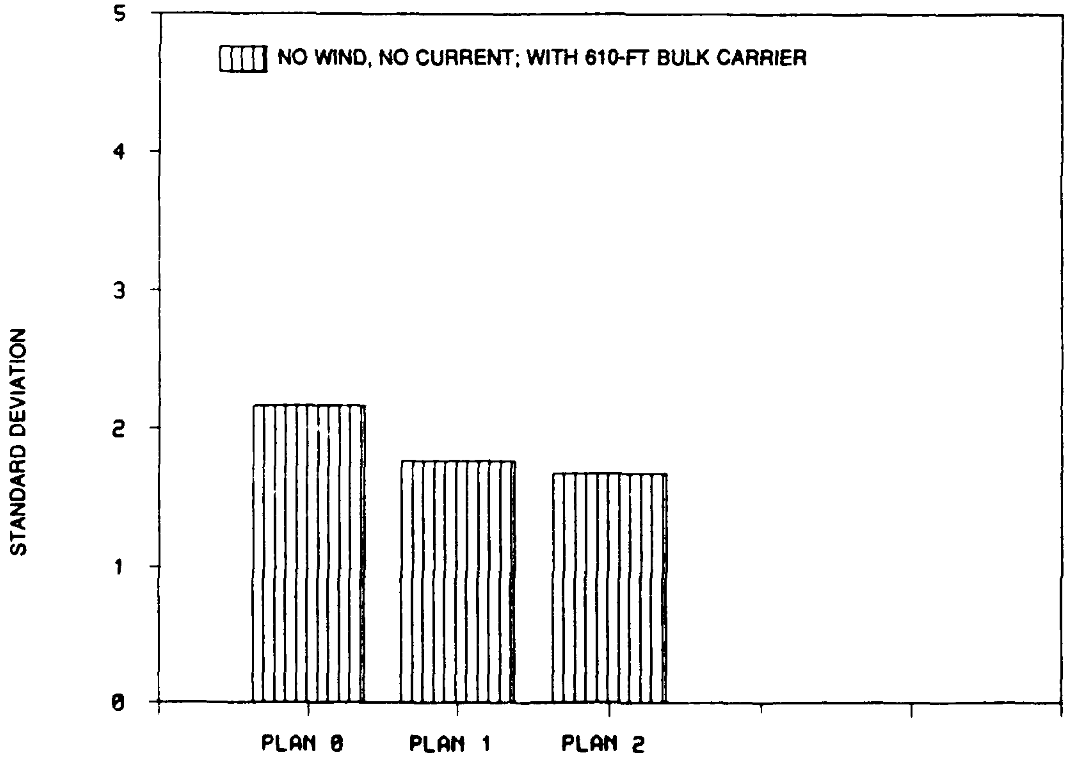


b. Standard deviation

Figure 42. Mean rate of turn and standard deviation, area B, Plans 0 and 1, with and without current

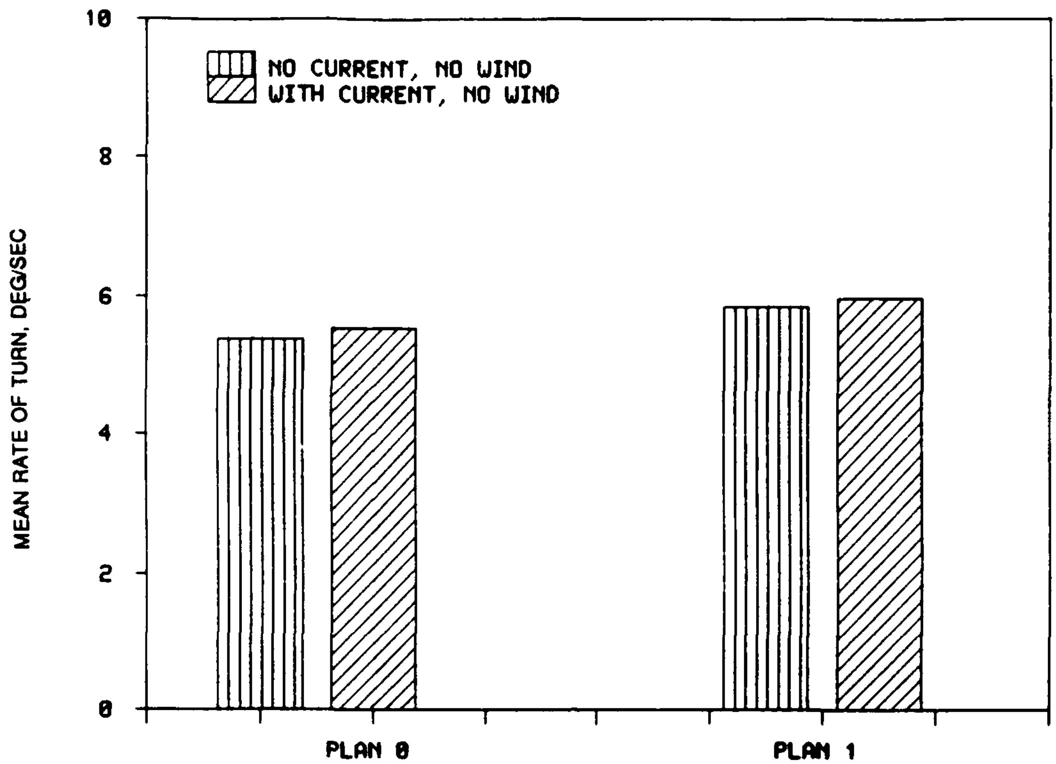


a. Mean rate of turn

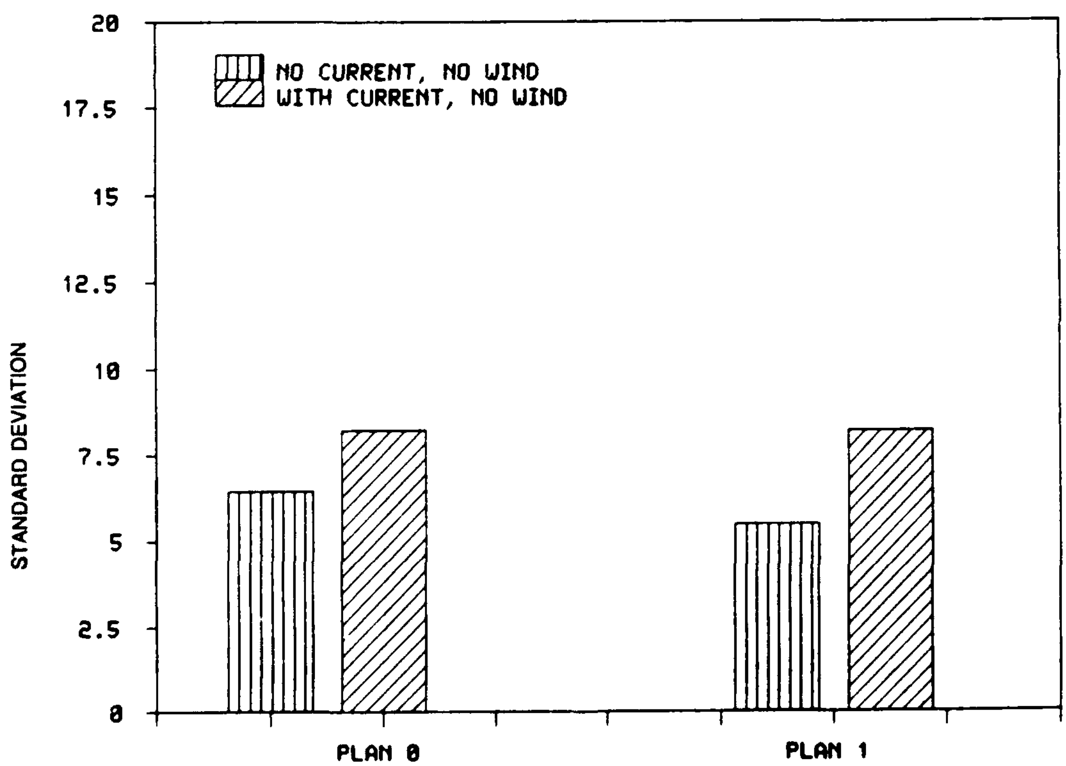


b. Standard deviation

Figure 43. Mean rate of turn and standard deviation, area B, Plans 0, 1, and 2, no current and no wind

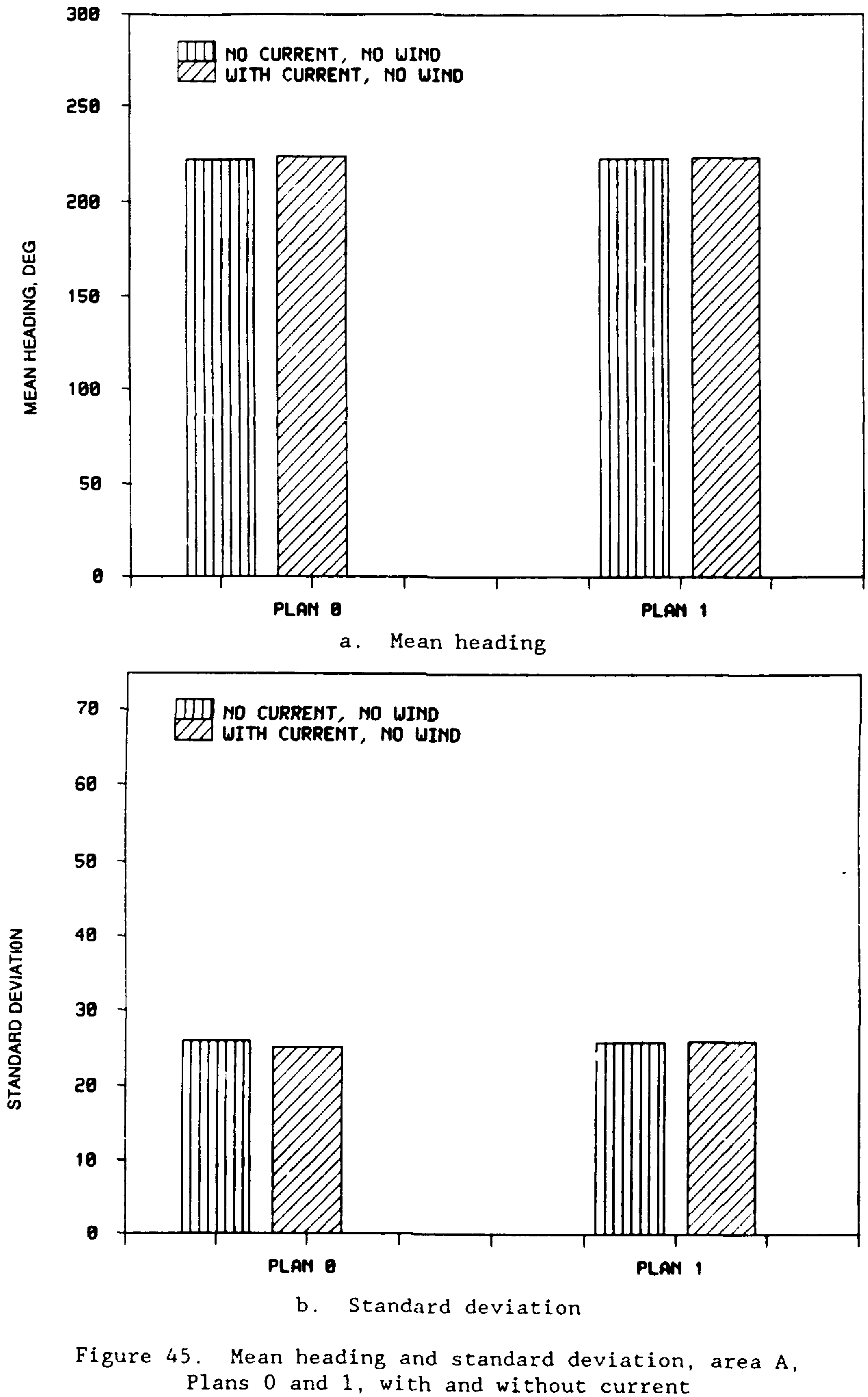


a. Mean rate of turn



b. Standard deviation

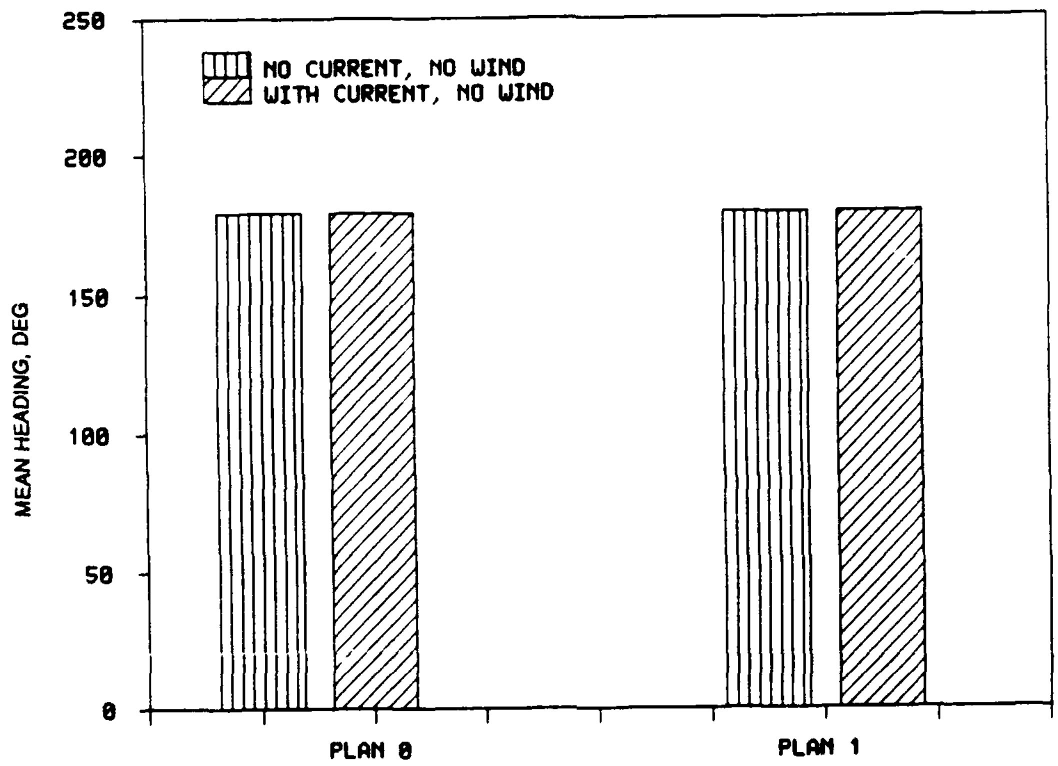
Figure 44. Mean rate of turn and standard deviation, area C, Plans 0 and 1, with and without current



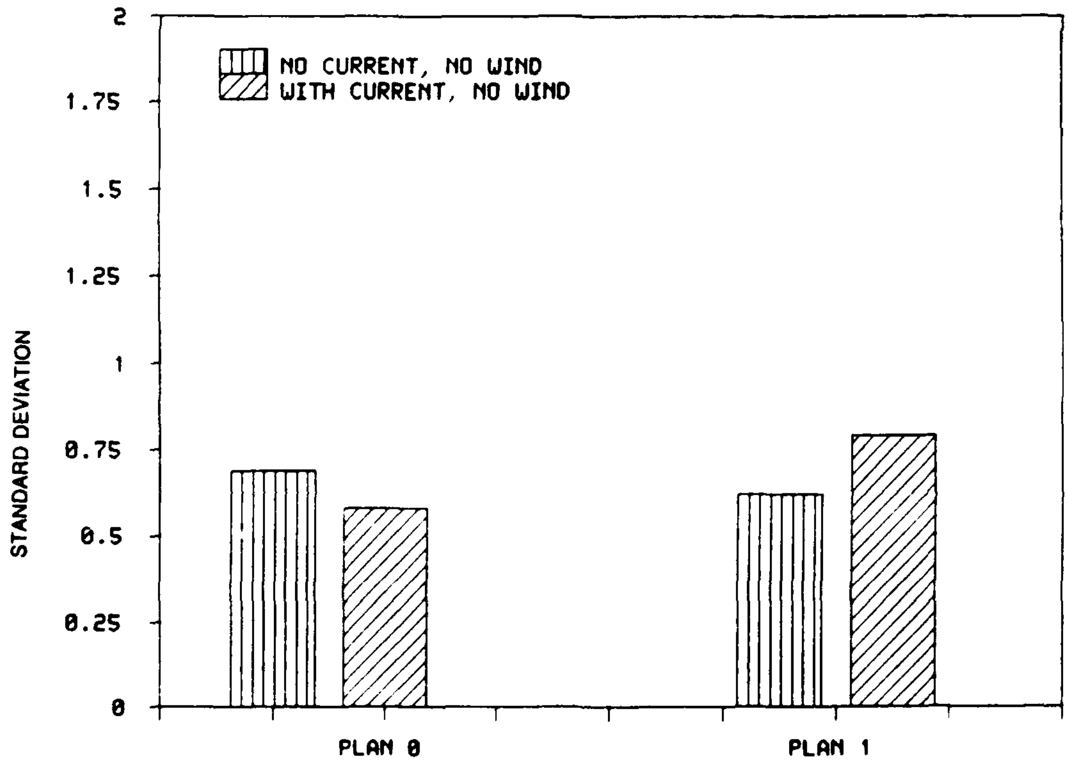
a. Mean heading

b. Standard deviation

Figure 45. Mean heading and standard deviation, area A, Plans 0 and 1, with and without current

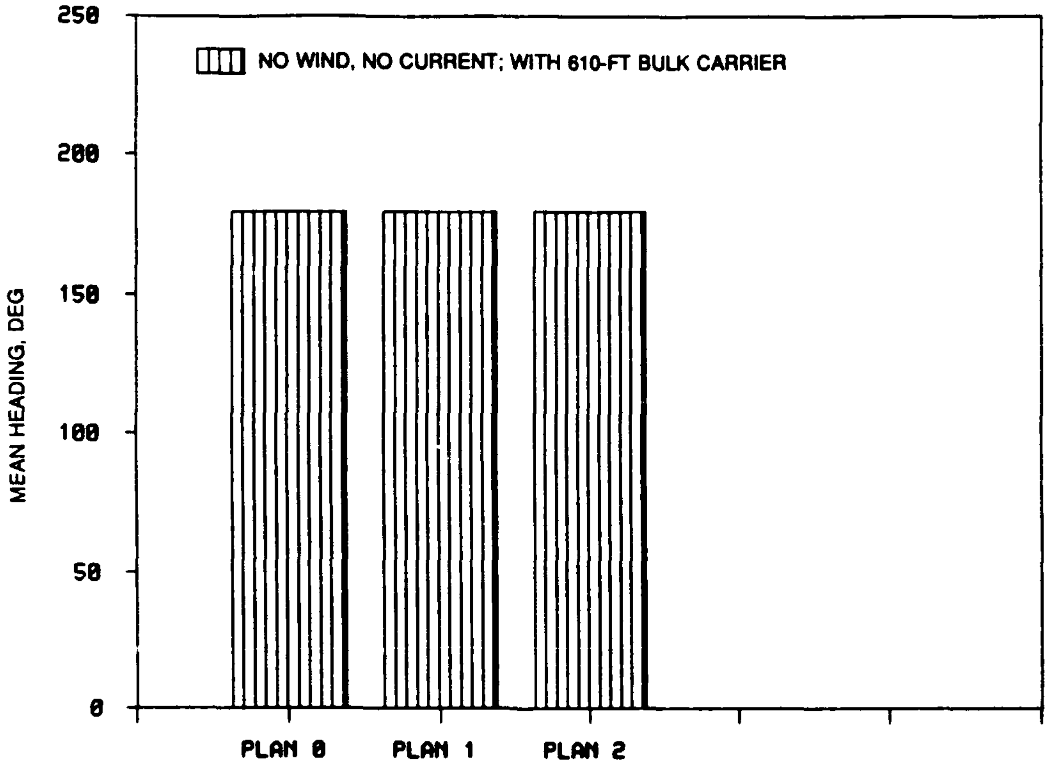


a. Mean heading

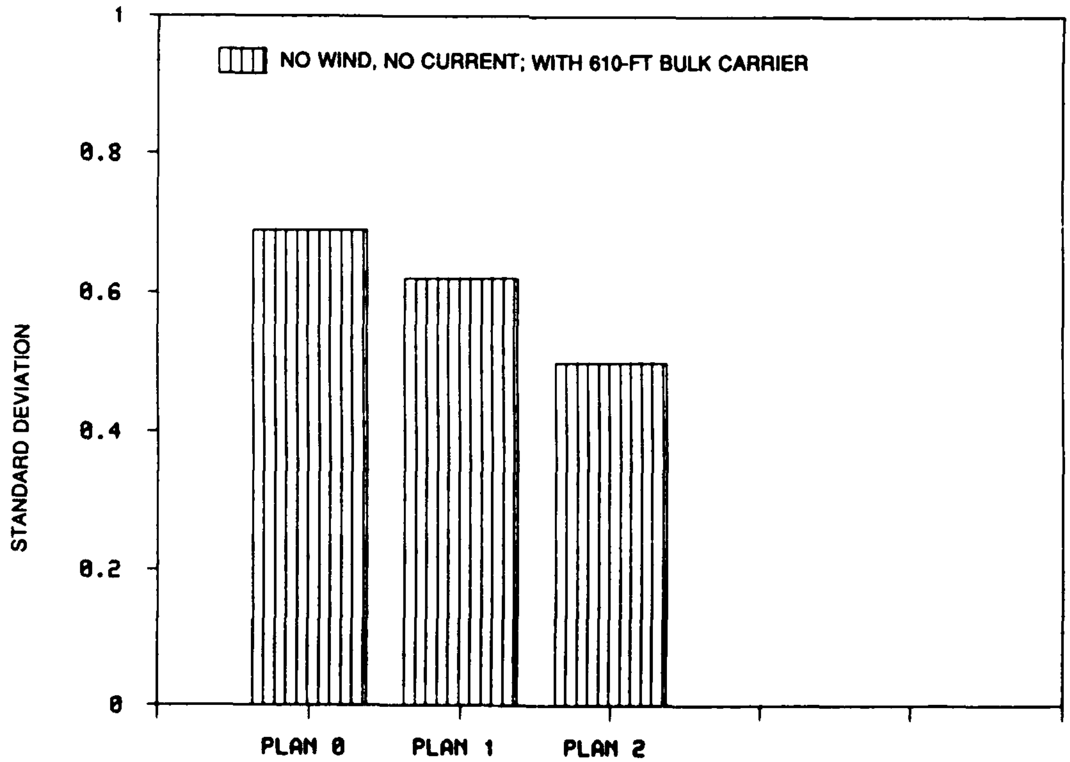


b. Standard deviation

Figure 46. Mean heading and standard deviation, area B, Plans 0 and 1, with and without current

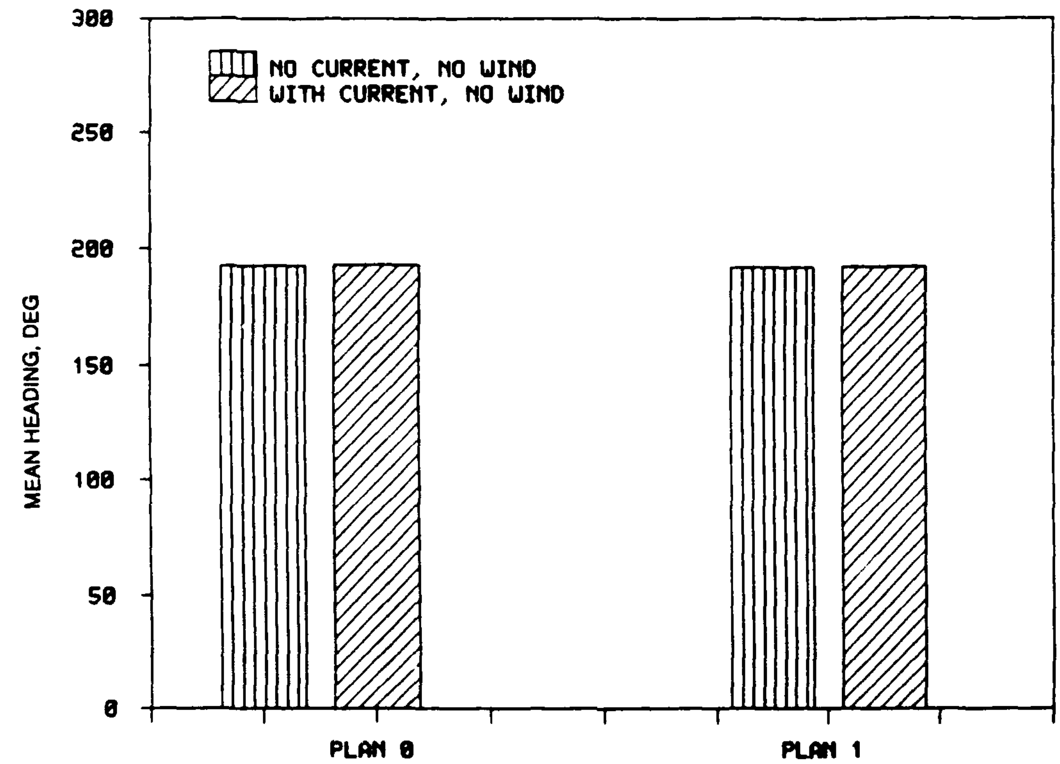


a. Mean heading

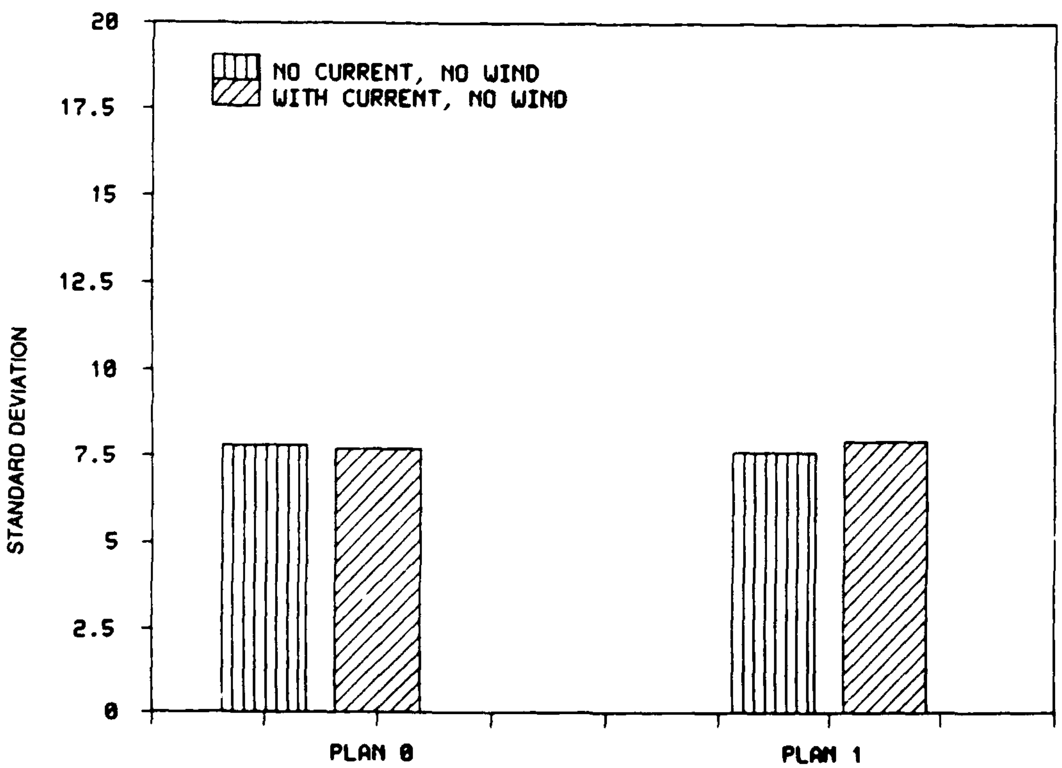


b. Standard deviation

Figure 47. Mean heading and standard deviation, area B, Plans 0, 1, and 2, no current and no wind

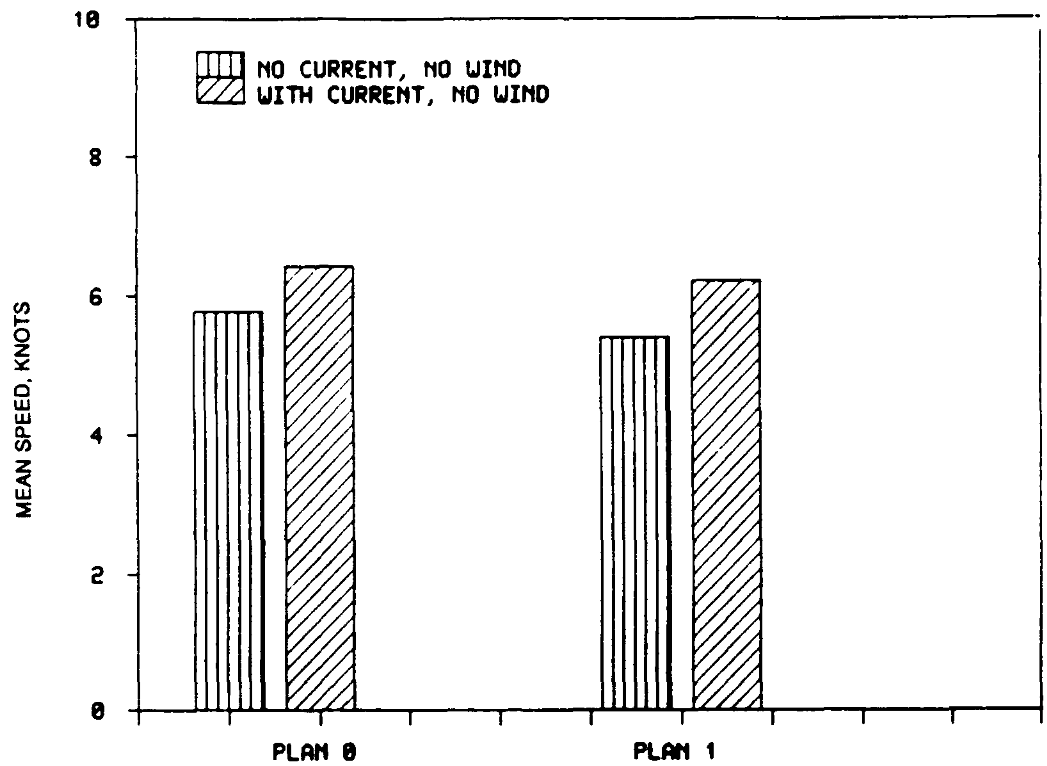


a. Mean heading

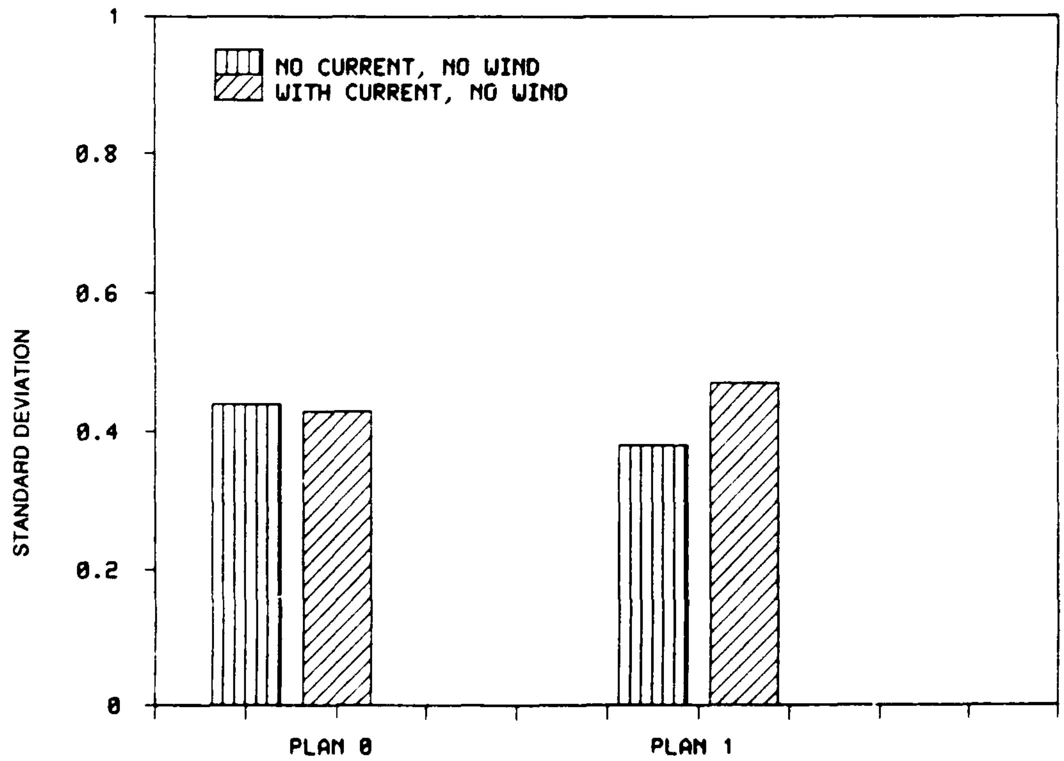


b. Standard deviation

Figure 48. Mean heading and standard deviation, area C, Plans 0 and 1, with and without current

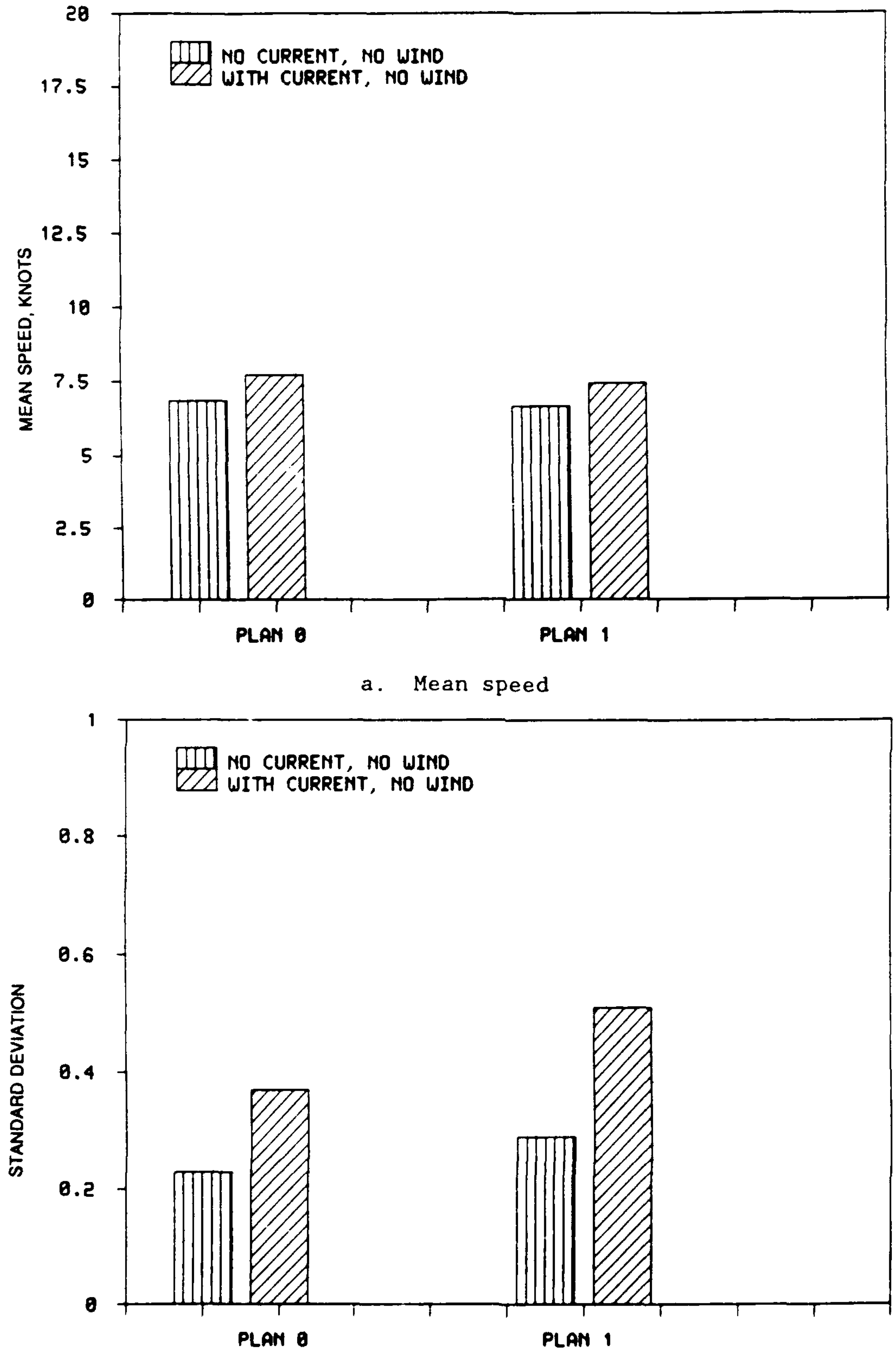


a. Mean speed



b. Standard deviation

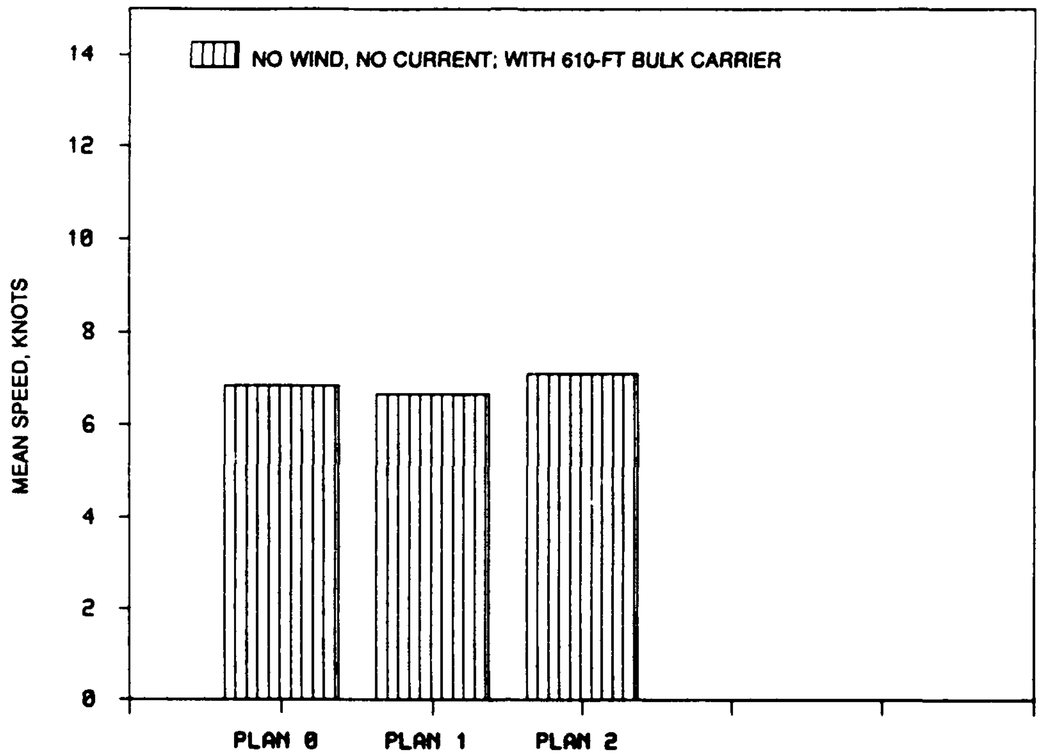
Figure 49. Mean speed and standard deviation, area A, Plans 0 and 1, with and without current



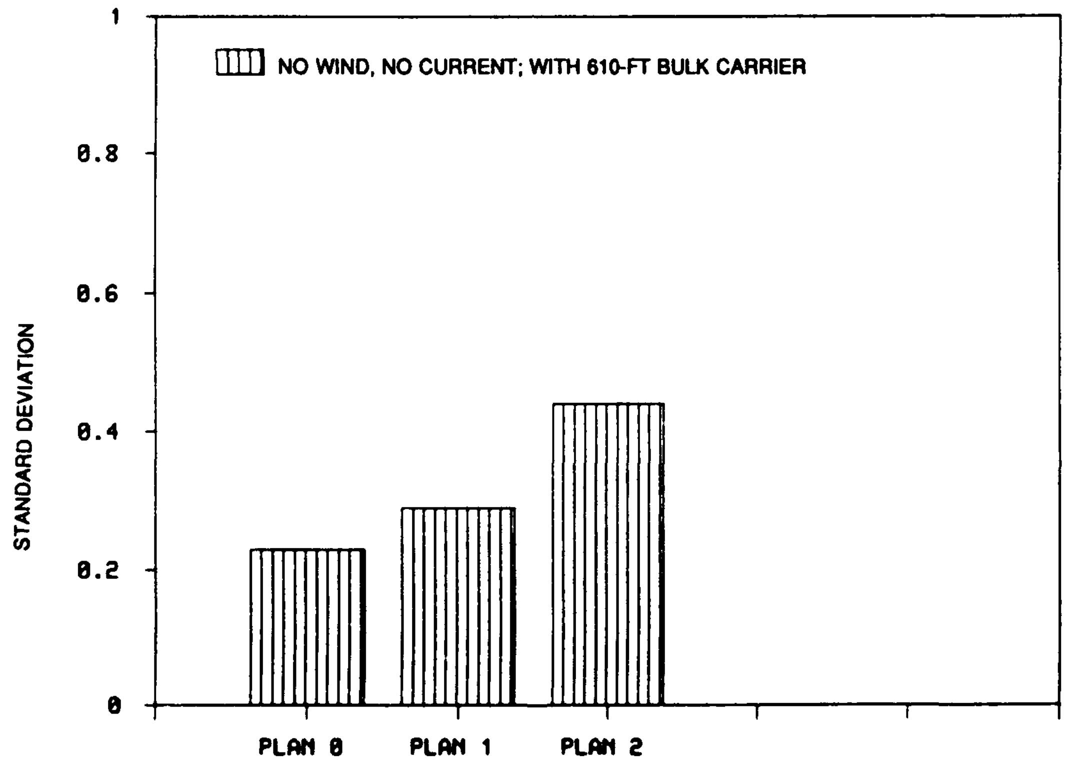
a. Mean speed

b. Standard deviation

Figure 50. Mean speed and standard deviation, area B, Plans 0 and 1, with and without current

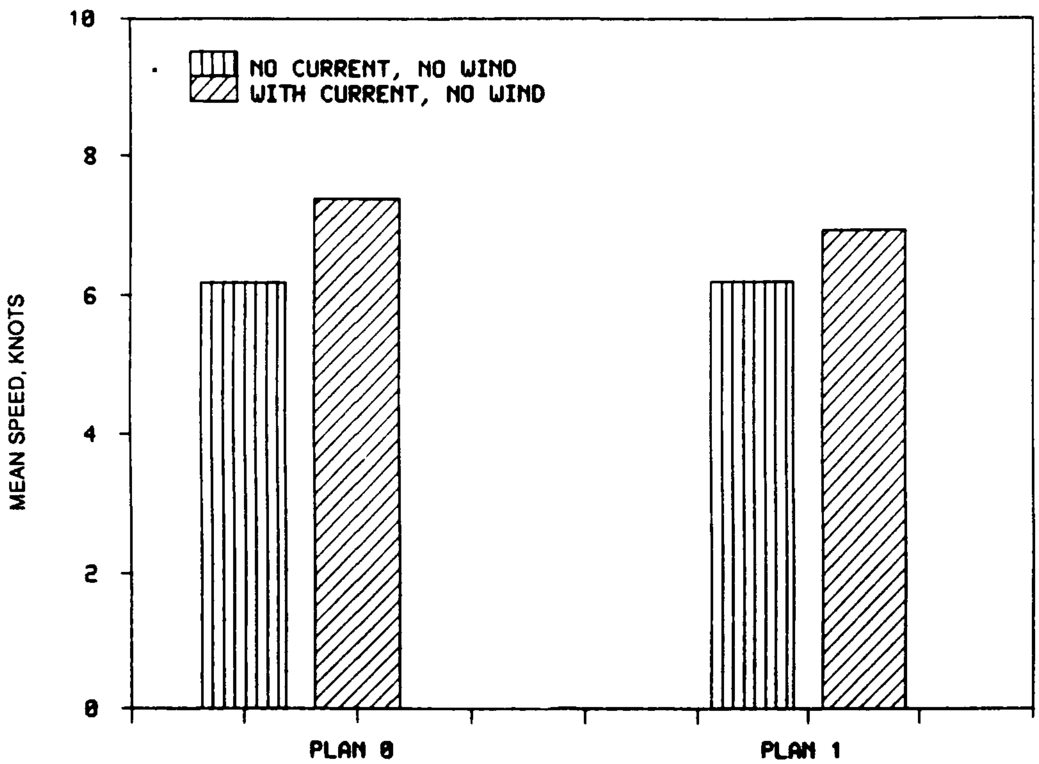


a. Mean speed

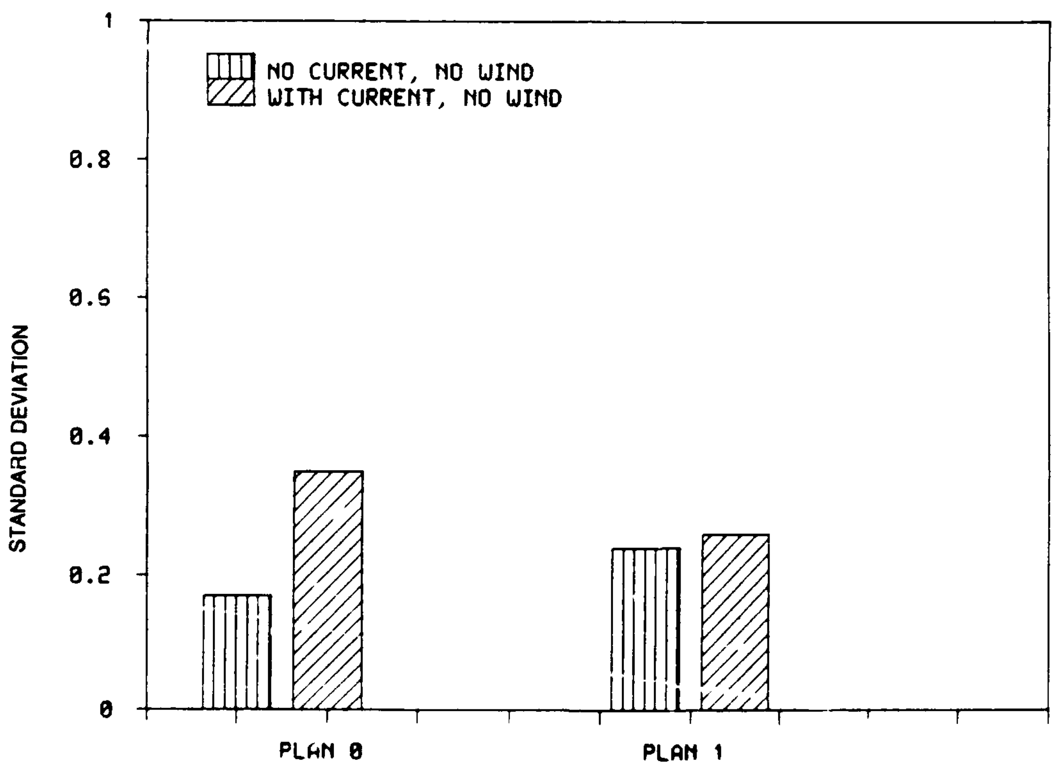


b. Standard deviation

Figure 51. Mean speed and standard deviation, area B, Plans 0, 1, and 2, no current and no wind



a. Mean speed



b. Standard deviation

Figure 52. Mean speed and standard deviation, area C, Plans 0 and 1, with and without current

APPENDIX A: PILOT QUESTIONNAIRES

SACRAMENTO RIVER DEEP WATER SHIP CHANNEL
FINAL DEBRIEFING QUESTIONNAIRE

The purpose of this questionnaire is to get your final thoughts and ideas about the possible effect of deepening and widening the turn of the Sacramento River (upper reach: from the Sacramento Harbor to mile 35) based on the simulation runs you have just made.

In your opinion, based on the simulation runs:

1. How will deepening the channel affect ship maneuverability and safety?

2. How will the widening of the turn affect ship maneuverability and safety?

3. Is there any difference in the bank force between the existing and the 35 foot channel?

4. Is there any difference in the effect of the current between the existing and the 35 foot channel?

5. How will widening the channel (250 feet wide x 35 feet deep) affect ship maneuverability and safety?

6. Which plan is needed in term safety and maneuverability?

    1. Plan 0 : 30 feet deep, 200 feet wide
    2. Plan 1 : 35 feet deep, 250 feet wide at the turn only
    3. Plan 2 : 35 feet deep, 250, 250 feet wide through out the channel

7. Do you have any suggestion for improving the simulation? Think about currents, waves, bank forces, console equipment, visual scene, radar scene, vessel behavior....

8. On a scale 0 to 10 (10 being excellent), what is your overall opinion of the simulator and the Sacramento River (upper reach) simulation.

SACRAMENTO RIVER DEEPWATER SHIP CHANNEL
FINAL DEBRIEFING QUESTIONNAIRE

The purpose of this questionnaire is to get your final thoughts and ideas about the possible effect of deepening and widening the turn of the Sacramento River (upper reach: from the Sacramento Harbor to mile 35) based on the simulation runs you have just made.

In your opinion, based on the simulation runs:

1. How will deepening the channel affect ship maneuverability and safety?

Deepening would increase ship maneuverability and thereby increase safety.

2. How will the widening of the turn affect ship maneuverability and safety?

Turn areas represent the most difficult area for a pilot to maintain a proper position in the channel as ship movement, direction, etc., are constantly changing. Widening the turns removes just a little further bank and bottom contours causing adverse influence on the vessel.

3. Is there any difference in the bank force between the existing and the 35-foot channel?

The increased drafts would increase the bank effects.

4. Is there any difference in the effect of the current between the existing and the 35-foot channel?

Current will determine the speed of the vessel through the water. Speed through the water to some degree will influence the magnitude of bank effects.

5. How will widening the channel (250 feet wide × 35 feet deep) affect ship maneuverability and safety?

A wider channel will increase the maneuverability of the vessel thereby increasing the safety factors for that vessel. Additionally, reduced water turbulence as the vessel passes increases safety to persons on boats at the edge of the channel. It would also seem reduced water turbulence might reduce bank erosion.

6. Which plan is needed in terms of safety and maneuverability?

1. Plan 0 : 30 feet deep, 200 feet wide
2. Plan 1 : 35 feet deep, 250 feet wide at the turn only
3. ✓ Plan 2 : 35 feet deep, 250 feet wide through out the channel

In terms of safety and maneuverability.

7. Do you have any suggestion for improving the simulation? Think about currents, waves, bank forces, console equipment, visual scene, radar scene, vessel behavior.....

No.

8. On a scale 0 to 10 (10 being excellent), what is your overall opinion of the simulator and the Sacramento River (upper reach) simulation?

9

SACRAMENTO RIVER DEEPWATER SHIP CHANNEL
FINAL DEBRIEFING QUESTIONNAIRE

The purpose of this questionnaire is to get your final thoughts and ideas about the possible effect of deepening and widening the turn of the Sacramento River (upper reach: from the Sacramento Harbor to mile 35) based on the simulation runs you have just made.

In your opinion, based on the simulation runs:

1. How will deepening the channel affect ship maneuverability and safety?

A 35′ deep channel will increase safety on vessels not loaded beyond 34′ of draft but should slightly decrease safety on vessels 35′ of draft and above. Ship maneuverability decreases as the ratio of under keel/draft decreases.

2. How will the widening of the turn affect ship maneuverability and safety?

It will allow more width for set and drift. A wider channel will lessen the effect of bank suction and will allow the pilot more room for error.

3. Is there any difference in the bank force between the existing and the 35-foot channel?

As programmed, the bank suction seems to have a greater effect on 35′ deep vessel in the 35′ channel than it had on the 30′ deep vessel in the 30′ channel.

4. Is there any difference in the effect of the current between the existing and the 35-foot channel?

The current seemed to have a greater effect in the 35′ channel in Areas A & C but not in Area B.

5. How will widening the channel (250 feet wide × 35 feet deep) affect ship maneuverability and safety?

The wider deeper channel would greatly increase maneuverability and safety. The vessels would feel less bank suction, have more width to allow for set & drift and allow for pilot error.

6. Which plan is needed in terms of safety and maneuverability?

1. Plan 0 : 30 feet deep, 200 feet wide
2. Plan 1 : 35 feet deep, 250 feet wide at the turn only
3. ✓ Plan 2 : 35 feet deep, 250 feet wide through out the channel

7. Do you have any suggestion for improving the simulation? Think about currents, waves, bank forces, console equipment, visual scene, radar scene, vessel behavior.....

The simulated wind force seemed stronger than what I would expect the effect would be on a loaded vessel. The bank effect seemed less than what I would expect.

8. On a scale 0 to 10 (10 being excellent), what is your overall opinion of the simulator and the Sacramento River (upper reach) simulation?

I rate the simulator at about 8.

I. Simulator

1) When color is working properly the simulator presents an accurate enough picture to obtain good test results.
2) The gods eye view screen helps make up for Loss at Depth Perception.
3) The swing indicator assists in steering when foreground is unclear.

II. Program

1) Test vessel is too small for accurate channel testing.
   A) The vessels which would normally load to 35' Draft are generally larger in beam and LOA than 610 ft.
   B) A vessel of 665' to 700' in length and 105' in beam would be more appropriate to test for channel requirements.
2) Handling Characteristics
   A) Simulator rudder power seems greater than most vessels with deep drafts.
      1) Increased rudder power has allowed us to run faster and recover quicker than we would be able to under actual conditions.
   B) Wind effect - seemed stronger than would be experienced on a loaded vessel.
   C) Current effect - seemed to be programmed correctly.
   D) Bank effect
      1) Area (A) - seemed less by at least 25% of actual effect.
      2) Area (B) - Less by at least 50% of actual effect.
      3) Area (C) - Less by about 10% of actual effect.
      4) Shears created by cut outs in Area B & C were greater than experienced on similar vessels.

III. Channel

1) I recommend a 250' wide 35' deep channel.
   1) It would increase safety and maneuverability.
   2) It would decrease bank effect.
   3) It would allow for faster transits.
   4) It would lessen bank erosion due to large vessels transiting.

SACRAMENTO RIVER DEEPWATER SHIP CHANNEL
FINAL DEBRIEFING QUESTIONNAIRE

The purpose of this questionnaire is to get your final thoughts and ideas about the possible effect of deepening and widening the turn of the Sacramento River (upper reach: from the Sacramento Harbor to mile 35) based on the simulation runs you have just made.

In your opinion, based on the simulation runs:

1. How will deepening the channel affect ship maneuverability and safety?

It will make the vessels harder to handle due to the increased weight and bank forces. Deeper ships are usually larger ships.

2. How will the widening of the turn affect ship maneuverability and safety?

It will greatly increase the safety margin allowing for the larger vessels. All turns should be widened.

3. Is there any difference in the bank force between the existing and the 35-foot channel?

Yes. Bank forces are more noticeable with deepened channel.

4. Is there any difference in the effect of the current between the existing and the 35-foot channel?

None noticed for depth but in 250′ widened channel, current had less effect on the handling of the vessel in the turns.

5. How will widening the channel (250 feet wide × 35 feet deep) affect ship maneuverability and safety?

Not only will it allow more room for error, (i.e. allowance for leeway and not being on exact center) but if channel is widened to begin with, you will have less bank erosion and therefore less maintenance dredging later. (Dig it now at today's dollars).

6. Which plan is needed in terms of safety and maneuverability?

1. Plan 0 : 30 feet deep, 200 feet wide
2. Plan 1 : 35 feet deep, 250 feet wide at the turn only
3. ✓ Plan 2 : 35 feet deep, 250 feet wide through out the channel

You know the Port of Sacramento and the shippers will want to run larger vessels up here if they have a deeper channel. You may as well do it right the first time.

7. Do you have any suggestion for improving the simulation? Think about currents, waves, bank forces, console equipment, visual scene, radar scene, vessel behavior.....

To be truly indicative for narrow/shallow simulation you must program the "squat" factor in.

8. On a scale 0 to 10 (10 being excellent), what is your overall opinion of the simulator and the Sacramento River (upper reach) simulation?

9

SACRAMENTO RIVER DEEPWATER SHIP CHANNEL
FINAL DEBRIEFING QUESTIONNAIRE

The purpose of this questionnaire is to get your final thoughts and ideas about the possible effect of deepening and widening the turn of the Sacramento River (upper reach: from the Sacramento Harbor to mile 35) based on the simulation runs you have just made.

In your opinion, based on the simulation runs:

1. How will deepening the channel affect ship maneuverability and safety?

There shouldn't by any change at all. The port and agenties will load the ships deeper.

2. How will the widening of the turn affect ship maneuverability and safety?

You would have less bank force, so the ship would maneuver alot easier around the turns.

3. Is there any difference in the bank force between the existing and the 35-foot channel?

No. There wouldn't be if the existing channel was maintained. There is alot of shoaling on the turns as it exists today.

4. Is there any difference in the effect of the current between the existing and the 35-foot channel?

No.

5. How will widening the channel (250 feet wide × 35 feet deep) affect ship maneuverability and safety?

It would give you that much more room for set a drift on windy days, and also maneuvering if something should happen to the vessel. (Steering/engine).

6. Which plan is needed in terms of safety and maneuverability?

1. Plan 0 : 30 feet deep, 200 feet wide
2. Plan 1 : 35 feet deep, 250 feet wide at the turn only
3. ✓ Plan 2 : 35 feet deep, 250 feet wide through out the channel

7. Do you have any suggestion for improving the simulation? Think about currents, waves, bank forces, console equipment, visual scene, radar scene, vessel behavior.....

No.

8. On a scale 0 to 10 (10 being excellent), what is your overall opinion of the simulator and the Sacramento River (upper reach) simulation?

9

SACRAMENTO RIVER DEEPWATER SHIP CHANNEL
FINAL DEBRIEFING QUESTIONNAIRE

The purpose of this questionnaire is to get your final thoughts and ideas about the possible effect of deepening and widening the turn of the Sacramento River (upper reach: from the Sacramento Harbor to mile 35) based on the simulation runs you have just made.

In your opinion, based on the simulation runs:

1. How will deepening the channel affect ship maneuverability and safety?

Deepening the channel will make the maneuverability of the ships much more difficult.

2. How will the widening of the turn affect ship maneuverability and safety?

Widening turn would help a great deal toward handling the deeper draft.

3. Is there any difference in the bank force between the existing and the 35-foot channel?

Approx. the same with more ship's rudder used.

4. Is there any difference in the effect of the current between the existing and the 35-foot channel?

No difference.

5. Do you have any suggestion for improving the simulation? Think about currents, waves, bank forces, console equipment, visual scene, radar scene, vessel behavior.....

Everything seems to be well however this is the first simulator that I have contact.

6. On a scale 0 to 10 (10 being excellent), what is your over all opinion of the simulator and the Sacramento River (upper reach) simulation.

I would give this an (8) because it does give you the bank action and also going around the super highway turn which in most cases is always difficult.

SACRAMENTO RIVER DEEPWATER SHIP CHANNEL
FINAL DEBRIEFING QUESTIONNAIRE

The purpose of this questionnaire is to get your final thoughts and ideas about the possible effect of deepening and widening the turn of the Sacramento River (upper reach: from the Sacramento Harbor to mile 35) based on the simulation runs you have just made.

In your opinion, based on the simulation runs:

1. **How will deepening the channel affect ship maneuverability and safety?**

I don't think it would affect the safety probably need more rudder.

2. **How will the widening of the turn affect ship maneuverability and safety?**

Shouldn't make any difference.

3. **Is there any difference in the bank force between the existing and the 35-foot channel?**

In the simulator there is more bank force.

4. **Is there any difference in the effect of the current between the existing and the 35-foot channel?**

No.

5. **Do you have any suggestion for improving the simulation? Think about currents, waves, bank forces, console equipment, visual scene, radar scene, vessel behavior.....**

If there was more indication as speed is increased for harder handling as occurs in ships also more indication of suction from banks.

6. **On a scale 0 to 10 (10 being excellent), what is your over all opinion of the simulator and the Sacramento River (upper reach) simulation.**

7

SACRAMENTO RIVER DEEP WATER SHIP CHANNEL
UPPER REACH - PILOT RATTING

PILOT:________________ DATE:________________
RUN CODE:________________ FILE NAME:________________
START TIME:________________ END TIME:________________

The purpose of this questionaire is to document your evaluation a observations concerning the simulator run you just completed. Feel fr to make any specific comments you feel will be helpful in interpretting your rating.

	Very simple								Very	difficul	
Area A	0	1	2	3	4	5	6	7	8	9	10
Area B	0	1	2	3	4	5	6	7	8	9	10
Area C	0	1	2	3	4	5	6	7	8	9	10

DIFFICULTY OF THE RUN

	Little									All of it	
Area A	0	1	2	3	4	5	6	7	8	9	10
Area B	0	1	2	3	4	5	6	7	8	9	10
Area C	0	1	2	3	4	5	6	7	8	9	10

AMOUNT OF ATTENTION REQUIRED

	Little									Tremendous	
Area A	0	1	2	3	4	5	6	7	8	9	10
Area B	0	1	2	3	4	5	6	7	8	9	10
Area C	0	1	2	3	4	5	6	7	8	9	10

DANGER OF GROUNDING

	Little									Tremendous	
Area A	0	1	2	3	4	5	6	7	8	9	10
Area B	0	1	2	3	4	5	6	7	8	9	10
Area C	0	1	2	3	4	5	6	7	8	9	10

DANGER OF HITTING AN OBJECT

	Bad									Very	good
Area A	0	1	2	3	4	5	6	7	8	9	10
Area B	0	1	2	3	4	5	6	7	8	9	10
Area C	0	1	2	3	4	5	6	7	8	9	10

REALISM OF THE HANDLING OF THE SIMULATOR

	Bad									Very	good
Area A	0	1	2	3	4	5	6	7	8	9	10
Area B	0	1	2	3	4	5	6	7	8	9	10
Area C	0	1	2	3	4	5	6	7	8	9	10

REALISM OF THE EFFECT OF THE CURRENT

	Bad									Very	good
Area A	0	1	2	3	4	5	6	7	8	9	10
Area B	0	1	2	3	4	5	6	7	8	9	10
Area C	0	1	2	3	4	5	6	7	8	9	10

REALISM OF THE EFFECT OF THE WIND

	Bad									Very	good
Area A	0	1	2	3	4	5	6	7	8	9	10
Area B	0	1	2	3	4	5	6	7	8	9	10
Area C	0	1	2	3	4	5	6	7	8	9	10

REALISM OF THE EFFECT OF THE BANK FORCE